Electronics &
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Canada's Magazine for High-Tech Discovery

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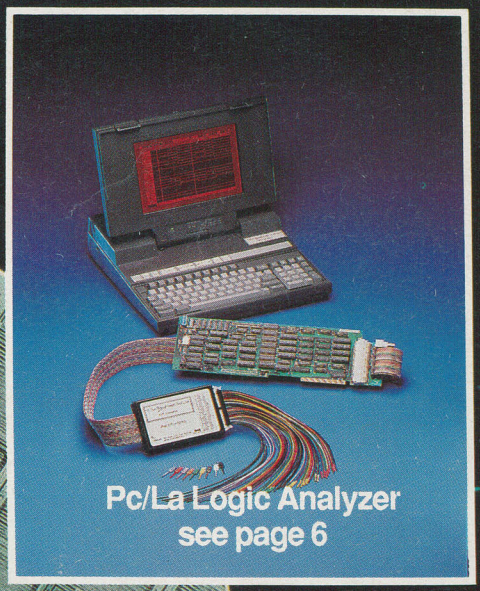
13TH Anniversary Issue !

Basic Electricity Series
Rocket Launch Controller
Using Smart FETs
Game Timer



Pc/La Logic Analyzer
see page 6

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EXCELTRONIX INTRODUCES 80486 FOR UNDER $4000

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BEST COMPACT 386SX

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New SX motherboard has all peripherals listed above on board leaving you with 6 expansion slots.

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Based on the Intel 80386 microprocessor, Phoenix BIOS, One 1.2MB Floppy Diskette Drive (Optional 360K 5.25" Floppy Drive or 720K 3.5" Floppy Drive or 1.44MB 3.5" Floppy Drive), socketed for 80387 math co-processor, 6 Expansion Slots, Two Serial Ports, One Parallel Port, Real Time Clock, Floppy Controller and Hard Drive Controller, 101 Enhanced Keyboard. Available with 32-bit memory in the following RAM configuarations: 2 Mb, 4MB, 8 MB, 16 MB. Features a small footprint, yet it can take as many cards and drives (including hard drives) as full-sized models.

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(10 MHz, 3-slot XT Compatible)

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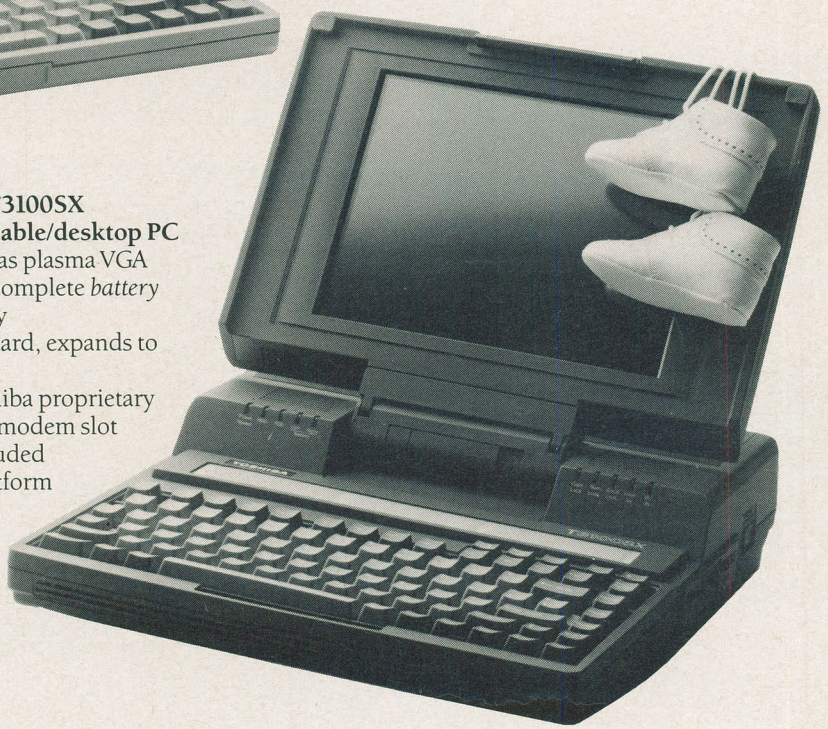

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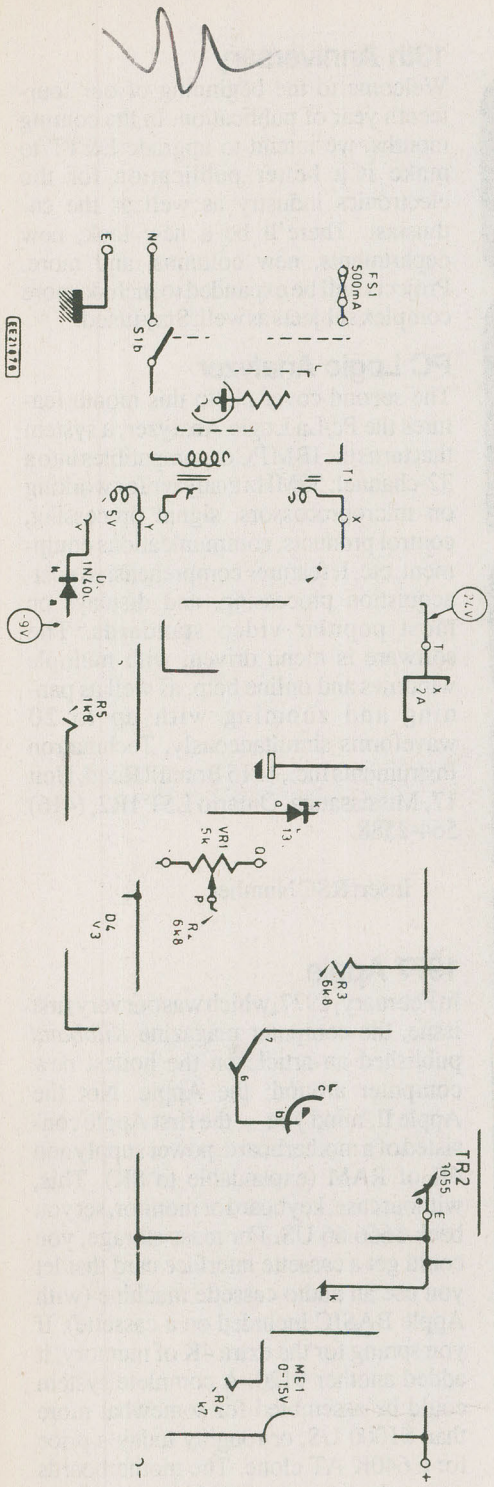

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Canada's Magazine for High-Tech Discovery

Volume 14, Number 2 February, 1990

FEATURES

Basic Electricity, Part 1 24
Beginning a new series.

Techie's Guide to C Programming, Part 14 32
Steve Rimmer's monthly programming guide.

Understanding SENSEFETS 48
Using Motorola's current-sensing FETs.

Designing with Logic, Part 1 34
Steve Rimmer begins a new series.

Industry views 36
Michael Doucet on economical ATE

PROJECTS

Rocket Launch Controller 8
Possesion Loop Alarm 20
Auto Light 12
Game Timer 16

INFORMATION

For Your Information 6
Software 27
Next Month 41
Subscriptions 41
Order Form 42
Books 46
Advertiser's Index 26

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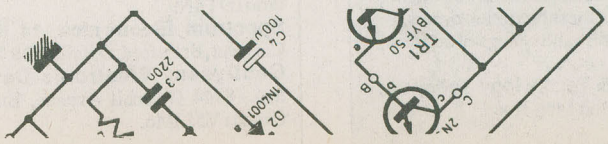

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Spectrum Electronics, 14 Knightswood Crescent, Brantford, Ontario N3R 7E6.

GeoDyssey Electronic Development Inc., 8744 Greenall Avenue, Burnaby, B.C., Canada V5J 3M6.

13th Anniversary
Welcome to the beginning of our fourteenth year of publication. In the coming months, we intend to upgrade E&TT to make it a better publication for the electronics industry as well as the enthusiast. There'll be a new look, new departments, new columns, and more. Projects will be expanded to include more complex subjects as well. Stay tuned.

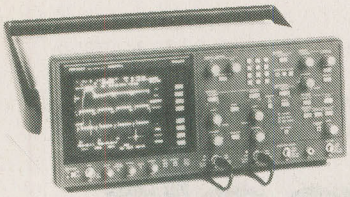
PC Logic Analyzer
The second cover photo this month features the Pc/La Logic Analyzer, a system that turns the IBM PC or compatibles into a 32-channel, 50MHz analyzer for working on microprocessors, signal processing, control products, communications equipment, etc. It features comprehensive post-acquistion processing, and displays on most popular video standards. The software is menu driven, with multiple windows and online help, as well as panning and zooming with up to 20 waveforms simultaneously. Techmatron Instruments Inc., 1415 Bonhill Road, Unit 17, Mississauga, Ontario L5T 1R2, (416) 564-2588.

Insert RSC Number

1977 Apple
In February, 1977, which was our very first issue, the computer magazine *Kilobaud* published an article on the hottest new computer around: the Apple. Not the Apple II, mind you — the first Apple consisted of a motherboard, power supply and 4K of RAM (expandable to 8K). This, without case, keyboard or monitor, set you back $666.66 US. For mass storage, you could get a cassette interface card that let you use an audio cassette machine (with Apple BASIC included on a cassette). If you sprang for the extra 4K of memory, it added another $120. A complete system could be assembled for somewhat more than $1000 US, or roughly today's price for a 640K AT clone. The motherboards seem to have been assembled one at a time; makes you wonder how many there are out there.

It's interesting to speculate whether people will look back on us the same way 13 years from now. "640K??? Are you *kidding?* A 20MHz clock??? How did you ever get anything *done?*"

For Your Information



Quad Power Supply

Good Will Instruments has introduced a quad output power supply with digital readouts, the Model GPQ3030D. It features parallel and series tracking, making higher voltage or current levels possible by doubling the supply's output. Channels 1 and 2 provide 0-30V at 0-3A, Channel 3 is 5V at 1A and Channel 4 has 5V at 3A. Duncan Instruments, 121 Milvan Drive, Toronto, Ontario M9L 1Z8, (416) 742-4448.

Circle No. 3 on Reader Service Card

New DMM

KB Electronics announces the addition of the DM 205 Digital Multimeter to its line of electronic test equipment. This compact meter features a rotary dial, DC volts to 1,000, AC volts to 750, DC current to 10A and resistance to 2M ohms. The DM 205 features a data hold features that holds the present reading when the leads are disconnected. KB Electronics, 1428 Speers Rd., Unit 8, Oakville, Ontario L6L 5M1, (416) 847-8588, Fax 847-8598.

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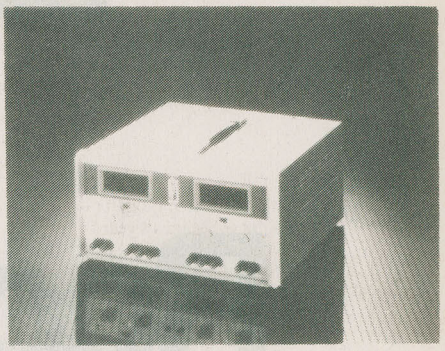
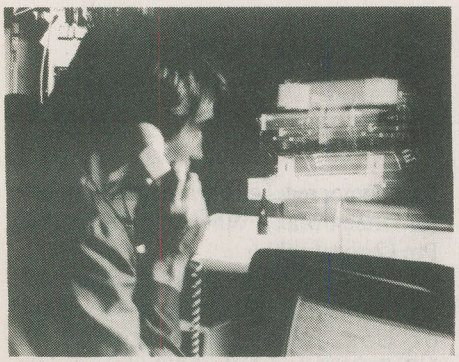


Digital Scope

A new dual-channel 300MHz scope offers 500 MS/s synchronous sampling rate on both channels for a 2ns single-shot resolution. The Philips PM 3323 also features 10-bit vertical resolution and four memories. The multiprocessor scope has IEEE-488 and RS232 interfaces with a built-in FFT facility as an option. Fluke Electronics Canada Inc., 400 Brittania Road E., Unit #1, Mississauga, Ontario L4Z 1X9, (416) 890-7600, Fax 890-6866.

Circle No. 5 on Reader Service Card

continued on page 39



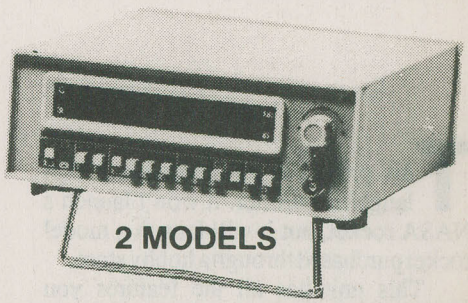
Supersmart Robot

Did you know that only 127 common words can make more than 3×10^{20} grammatically correct, meaningful sentences? Neither did we, but AT&T Bell Laboratories is experimenting with a robot arm that can understand and respond to all 300 quintillion questions, assertions and imperatives as they are spoken in normal human conversation. SAM, short for Speech Activated Manipulator, is part of Bell Lab's continuing research into speech recognition and machine intelligence. The arm's intelligence resides in eight computers, including an AT&T-designed parallel processor that performs up to a billion floating-point operations per second for speech recognition.

HAL 9000 may be online by 2001 as forecast...

MULTI-FUNCTION
Counters

GREAT FEATURES & PRICE!



HCF-100
Compact, lightweight 10 Hz to 100 MHz counter with four function performances. Features eight digit LED display, low power consumption circuit with functions for frequency, period, totalize and self check. **$259.**
Plus $10 for shipping & handling.

HCF-1000
Range 10 Hz to 1 GHz with 8-digit LED display, frequency, period, totalize and self check functions. **$495.**
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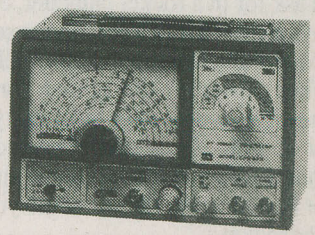

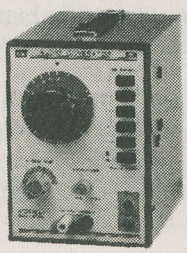

AUDIO GENERATOR
Five frequency ranges 10 MHz - 1 MHz, low distortion factor and six range output attenuator: 0, 10, 20, 30, 40 and 50 dB. 110 VAC power supply.
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PROJECT

Rocket Launch Controller

Control your igniter with this sophisticated timer circuit.

Derrick Renaud

This project is an automatic rocket launch controller. It won't launch a NASA rocket, but it will launch a model rocket purchased through a hobby store.

This unit has all the features you could ask for in a rocket launcher, except perhaps a voice output. It has a ten second countdown and then fires off the rocket by applying power to the igniter for four seconds. The count can be reset at any time or put on hold if any problems occur. It also has a safety switch to make sure no power is sent to the igniter while you are near the rocket.

Once built this controller can be used with any model rocket launch pad.

How It Works

The operation of the launcher is basically a countdown timer. U1 is an astable pulse generator that sets the clock speed of the counter. The counter can be made to go faster or slower by turning the trimmer resistor R1.

The clock pulses are sent to U3 (presettable binary up/down counter) which keeps control of the count in binary form. The counter is loaded with the binary value of ten when the power is turned on, or when the clear button (S1) is pressed. The display then shows 'c' which means ten, but for the purpose of the launcher it means *cleared* or *reset*. Pin 5 of U3 is the UP/DOWN control. When it is held in the high (1) state, the counter counts down. When it is held in the low (0) state, it counts up.

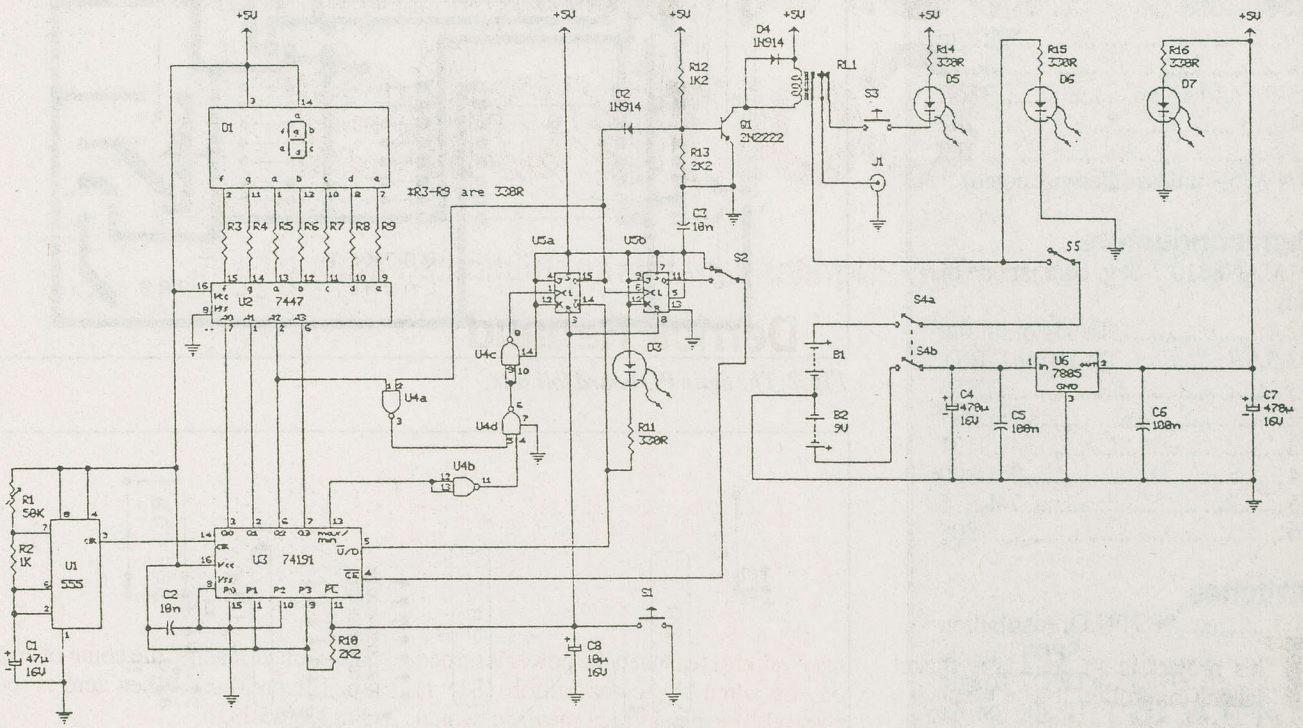
The display (D1) is a seven-segment common anode display, which is controlled by the BCD to seven-segment decoder (U2). U2's purpose is to convert the binary count of U3 into a readable decimal format displayed by D1.

The purpose of the four NAND gates of U4 is to send an active low pulse (normally high but goes low for one pulse) to U5 when the count of zero is reached or when a count of four is reached in the up direction.

Between the counts of ten to one the counter just counts down. But when the count reaches zero, power to the igniter has to be turned on for four seconds to set off the rocket. This is accomplished in the following manner. Pin 12 of U3 is the Max/Min control. This remains low until the counter reaches the count of zero/Min (or fifteen/Max). When zero is reached, Pin 12 goes high.

This causes an active low pulse to be sent from Pin 8 of U4c to toggle the output of U5a. When this happens the UP'/DOWN control of U3 is made low. Which makes the counter start to count upwards and the IGNITION Indicator (D3) is turned on. The output of U5a also turns on Q1 sending 5V through the relay (RL1) coil. This switches on power to the igniter.

The counter then counts upward from one to three with power still being sent to the igniter. When the counter reaches a count of four, the power to the igniter has to be turned off. When this is reached, U4a sees that a count of four has been reached in the up direction and then sends an active low pulse from pin 8 (U4) to toggle the output of U5a. Which in turn toggles the output of U5b (U5a has to be toggled twice before U5b is toggled because they are set up as a binary counter). Once this happens the UP'/DOWN control is reset back to the high state and the IGNITION Indicator is turned off. Q1 is turned off removing power from the relay coil. This in turn



S1 is the CLEAR button.
S2 is the HOLD/GO switch in HOLD position.
S3 is the IGNITOR TEST button.
S4 is the POWER switch.
S5 is the SAFETY switch in UNARMED position.
D1 is the COUNTDOWN display.
D3 is the COUNTDOWN DISPLAY.
D5 is the IGNITOR CONTINUITY indicator (cont. when lit).
D6 is the SAFETY indicator (armed when lit).
D7 is the POWER indicator.

Fig. 1. The schematic of the Rocket Launch Controller.

removes power from the igniter leads.

Once U5b is toggled, it puts a high state on the hold control of U3 (Pin 4) which stops the counter. This pin has to be low in order for the counter to continue counting. When you want to halt the counter by turning on the hold switch (S2), this also holds Pin 4 in a high state.

After the count of four, the counter is stopped and the rocket should be launched (if all goes well).

Construction

First you will need to etch and drill the two

Parts List

Capacitors

C1 .....47uF, 16V electrolytic
C2,C3 .....10nF ceramic
C4,C7 .....470uF, 16V electrolytic
C5,C6 .....100nF ceramic
C8 .....10uF, 16V electrolytic

Resistors

R1 .....50k trim
R2 .....1k
R3-9,11,14,15,16.....330R
R10,13 .....2k2
R12 .....1k2
(1/4W, 5% unless otherwise noted)

Semiconductors

D1MAN8610 7-Seg. com. anode display
D2,4 .....1N914 or similar
D3,5,6,7 .....T1-3/4 red L.E.D.
U1 555
U2 .....74LS47
U3 .....74LS191
U4 .....74LS00
U5 .....74LS76
U6 7805

Switches

S1,3 .....SPST N.O. Push button
S2 .....SPDT Toggle
S4 .....DPST or DPDT Toggle
S5 SPST or SPDT Toggle or Key switch

Miscellaneous

B1 9V Battery, clip & holder
B2 4 x 1.5V AAA Batteries & holder
J1 1/4" mono Phone jack (chassis mount)
RL1 Relay (Radio Shack # 275-243)

1/4" mono phone plug; 2 micro clips; 20 feet 2-conductor wire; 2 feet 8-conductor ribbon cable; wire; PC boards; cabinet; etc.

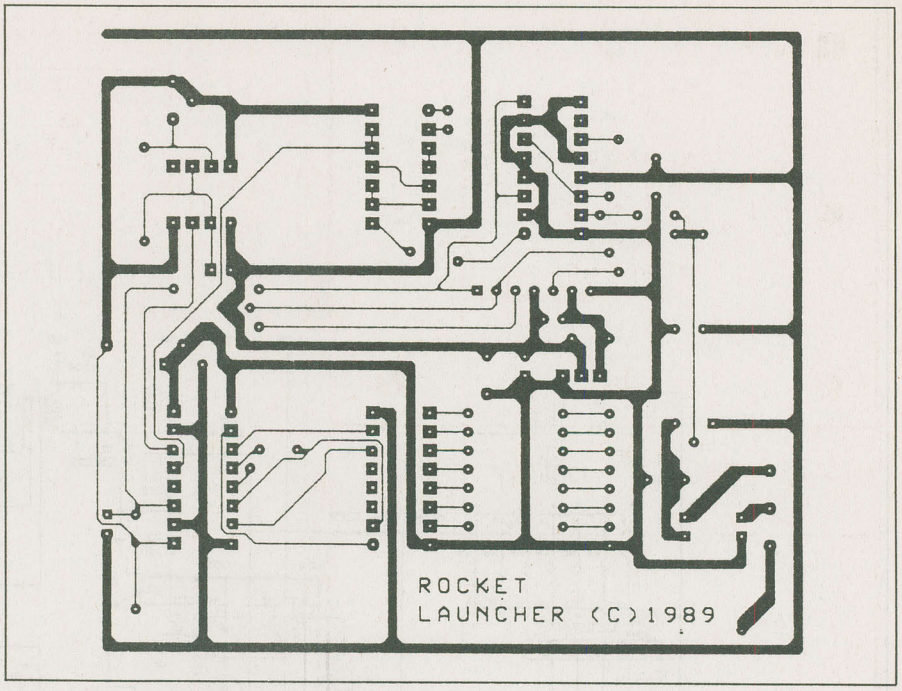


Fig. 2. The main PC board foli side.

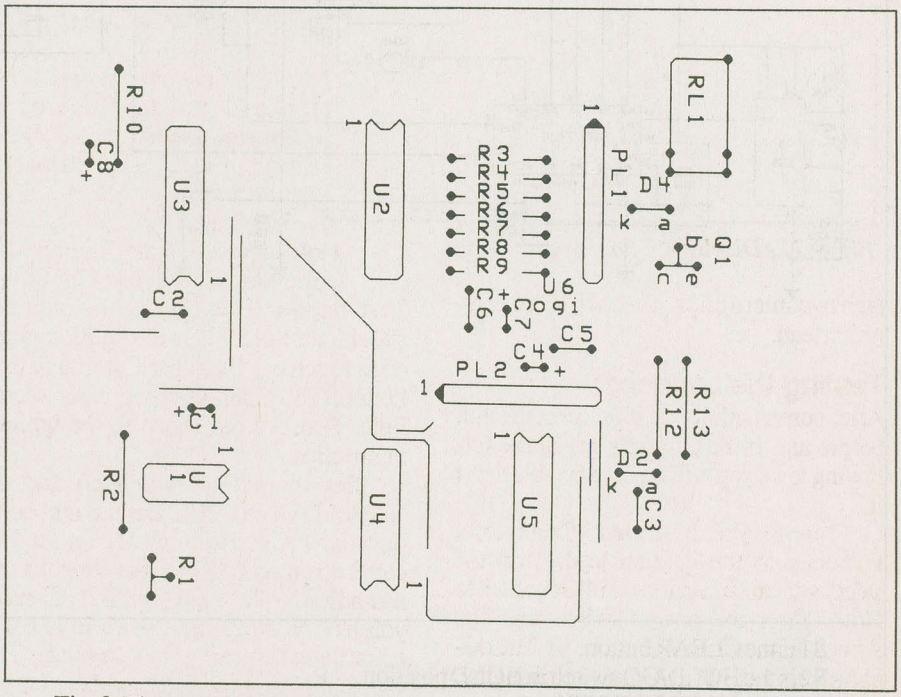


Fig. 3. The main PC board parts layout.

P.C. boards shown in Figures 2 & 3. Then you can install the parts as shown in the component location guides (Figures 4 & 5). Start by installing the sockets, resistors and diodes. Then install the capacitors, regulator, transistor, display and relay. Next install the nine jumpers.

Connect a piece of 8-wire ribbon cable between PL1 and PL3. Make sure to wire Hole 1 of PL1 to Hole 1 of PL3. Do the same with Holes # 2 through 8.

Cut and drill holes in the cabinet for all the switches, indicators and jack. Then install all the switches, indicators (except D1) and jack onto the cabinet.

Connect a piece of 7-wire ribbon cable to PL1. Wire the other end to the switches and indicators using other wire as necessary. See Figure 6. Next install the IC's. Then fasten the display board, main board and battery holders to the cabinet.

The instructions for construction given here are only a general guide. I leave all the cabinet construction to the builder. Refer to Figure 1 for the main schematic.

You will also need to connect a twenty foot piece of 2-conductor wire to a 1/8" phone plug on one end. At the other end at-

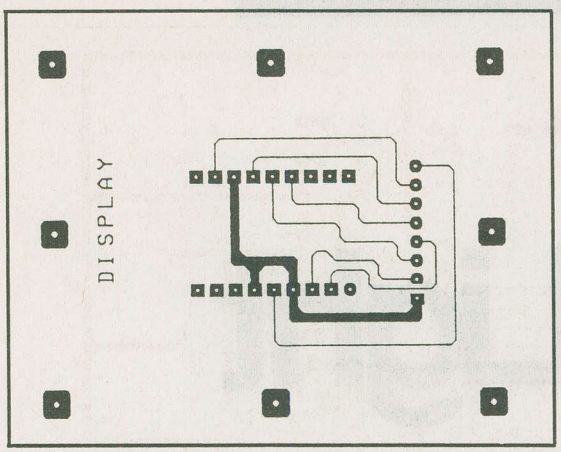


Fig. 4. The display PC board, foil side.

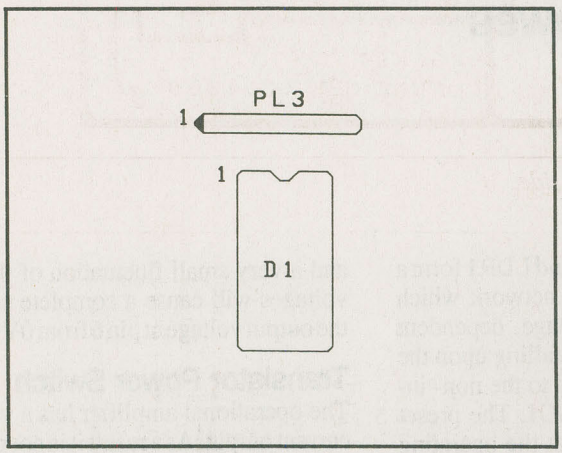


Fig. 5. The Display PC board parts layout.

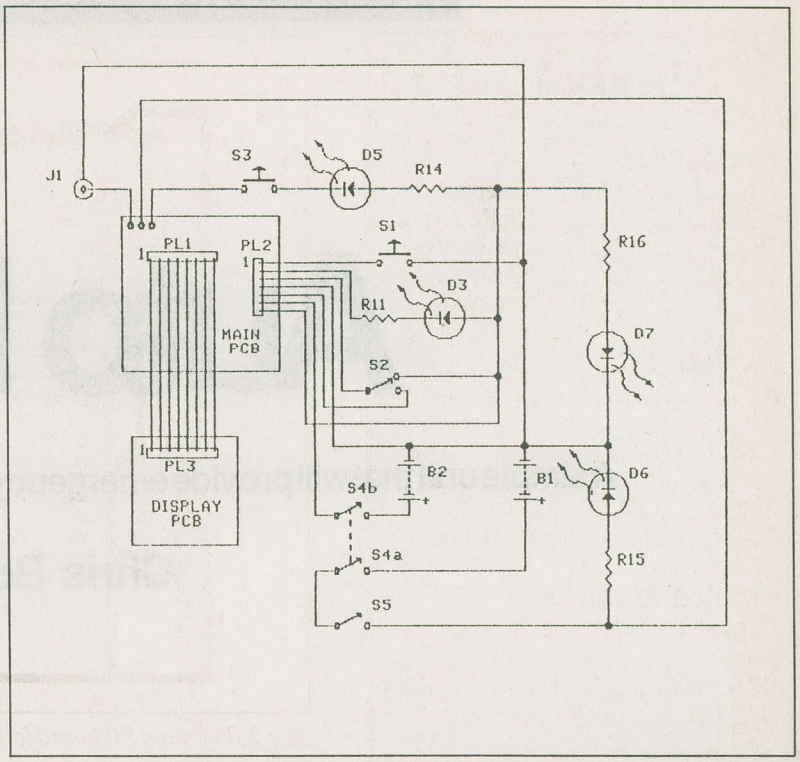


Fig. 6. The wiring diagram of the Rocket Lauch Controller.

tach two micro clips. This will be your ignition lead.

Testing the Launcher

After construction you should test the unit before use. If the unit fails any of the following tests you will have to troubleshoot it.

Install the batteries. Connect a voltmeter to the ignition lead. Turn the safety switch on. Set the Hold/Go switch to Hold. Turn the power switch on. The Armed indicator should not be lit. The display should show 'c' and not be changing. The voltmeter should show 0V. Set the Hold/Go switch to Go and the display should start counting down. When the count reaches zero the Ignition indicator should light. The voltmeter should still show 0V because the safety switch is on. When the count reaches four the Ignition indicator should go out and the display should remain at four.

Next turn the safety switch to off and the Armed indicator should light. Press Clear and the display will reset to 'c', and then start counting down. When the count reaches zero the voltmeter should read 6V . When the count goes back up to four the voltmeter will read 0V.

Set the Go/Hold switch to Hold. Press Clear. Remove the voltmeter. Press the Continuity Test button. The Continuity indicator should not light. Short the ignition micro clips together. Press the Continuity Test button. The Continuity indicator should light. Remove the short on the ignition micro clips.

Set the safety switch on and the Go/Hold switch to Go. Let the unit count down and adjust trimmer R1 for the best count down speed. Keep resetting the unit and adjusting R1 until you find the speed you like. You may find you will like it to count faster than one second intervals.

Once passing these tests, you are ready to use the controller on your model rocket.

Safety at the Launch Site

Always keep the power switch off when hooking up the ignition lead to the model rocket igniter. Use the safety switch while you have the unit on and are waiting for the all clear to launch or checking igniter continuity.10 - 9 - 8 - *Good Luck...* ■

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PROJECT

Auto Light

A simple unit that will provide emergency lighting or an automatic night light.

Chris Bowes

This project is designed to switch on a small, low voltage lamp automatically when the light level sensed by a Light Dependent Resistor (LDR) falls below a set level.

This is an interesting circuit in its own right and has a number of useful applications. These can include an automatic night light for use with a child or an emergency lighting system to take over illuminating a strategic area in the event of a power failure. The main active device in the project is the light dependent resistor. Light dependent resistors operate in the same way as variable resistors in so far that the actual resistance of the component can be made to vary.

In the case of a variable resistor or potentiometer you can manually alter the resistance by operating the rotating control of the component. With a light dependent resistor the amount of light falling upon the photo-sensitive area of the device governs the actual resistance of the component. In general when more light is shining on the LDR the resistance of the component is low and when very little light falls on it the resistance is high.

Circuit Description

The circuit diagram for the Autolight project appears in Fig. 1. Resistors R1 and R2 form a *fixed* (reference) voltage divider to produce a steady voltage of approximately 0.8V at the inverting input, pin 2 of IC1. Preset VR1 and LDR1 form a similar voltage dividing network which produces a *variable* voltage, dependent upon the amount of light falling upon the LDR, which is connected to the non- inverting input (pin 3) of IC1. The preset control is included so that the operating light level of the circuit may be accurately set.

IC1 is a CA3140 op amp which is configured in this circuit as a comparator. An operational amplifier is designed to amplify the difference between the two inputs by a factor which is determined by the ratio of the resistance between the signal and the inverting input and a similar resistance connected between the output and the inverting input.

When the op amp is set up as a comparator these two resistors are omitted and as a result the op amp has virtually an infinite gain. This is, in practice, limited by being restricted to the power supply rail voltages.

Under these circumstances the output state is determined by the voltages present at the two inputs. If the voltage at the non-inverting input (pin 3) is greater than the voltage present at the inverting input (pin 2) then the output at pin 6 will be the battery voltage.

If the conditions are reversed so that the voltage at pin 2 is greater than the voltage at pin 3 then the output at pin 6 will be 0 volts. The circuit is in fact very sensitive and a very small fluctuation of the input voltages will cause a complete swing of the output voltage at pin 6 from 0V to 9V.

Transistor Power Switch

The operational amplifier has a very low current output. As a result it is not possible for this device to directly switch the lamp on and off so a simple, single stage, transistor output switching amplifier, consisting of resistor R3 and transistor TR1 is used to carry out this task.

In this sort of application the transistor is used as a simple switch so that a small current flowing through the base/emitter junction is used to control a much larger current flowing through the collector/emitter circuit. When a very small current flows through the base emit-

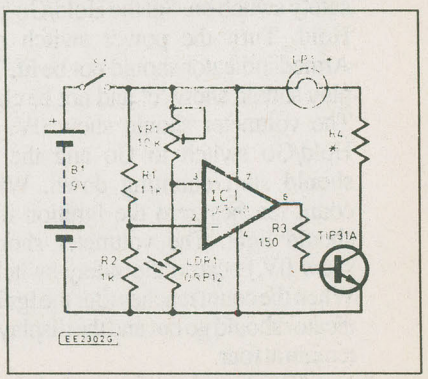


Fig. 1. The complete circuit of the Autolight.

Parts List

Resistors

R1 .....10k
R2 .....1k
R3 150
R4 .....150 0.5W (see text)
All 0.25W 5% carbon film

Potentiometer

VR1 .....10k horiz. trim

Semiconductors

TR1 ..... TIP31A *npn* power
IC1 .....CA3140 op amp

Miscellaneous

LDR1 light dependent resistor such as Philips 600-94001, ORP12, or photocell with 1000 ohms or less on-resistance.
S1 ..... SPST toggle switch
LP1 .....6.5V, 0.15A bulb (see text)
B1 .....9V battery
JK1 Min. jack connector to suit power supply (optional).

Perfboard, 38 holes x 18 holes; wire; bulb holder; 8-pin IC socket; battery connector; plastic case to suit.

ter circuit this allows a large current to flow through the collector/emitter circuit.

As soon as the current through the base/emitter ceases to flow then the current through the collector/emitter circuit is also prevented from flowing. The current will flow through the base/emitter as long as the voltage between the base and the emitter of the transistor exceeds 0.7V.

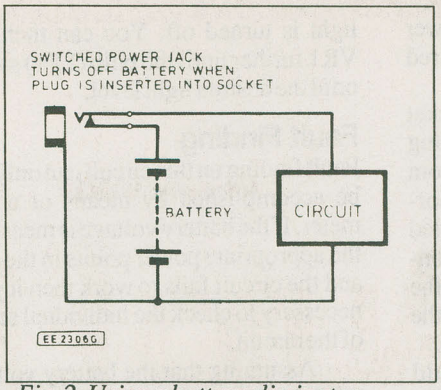


Fig. 2. Using a battery eliminator.

In actual fact, no matter what voltage is available at the base of the transistor the transistor will actually prevent the voltage between the base and the emitter exceeding 0.7V. Any excess voltage is converted to heat by the transistor and could cause serious damage to the transistor. In order to restrict the current flowing through the base/emitter circuit of the transistor to a safe level resistor R3 has been included in the circuit as a base protection resistor.

Lamp

The selection of the lamp operated by this circuit (LP1) presents a difficulty, since it appears that no suppliers have 9V bulbs available in their catalogues. The solution is to therefore use a lower voltage bulb and to adjust the voltage flowing through it by means of a series resistor (R4).

Although the values given in the component list will work quite happily they are by no means the only suitable combination. There are such a large number of bulbs available that the best strategy is for you to select a bulb and then select the appropriate value for R4 to suit your bulb using the formula:

R4 = (Vss-Vbulb)\Ibulb

Where Vss = the battery voltage, bulb = the voltage of the bulb and Ibulb = the current taken by the bulb.

Battery Eliminator

If you intend to operate this circuit as a child's nightlight, or in some similar situation where it must operate for a long period of time, you will probably find that normal 9V batteries are insufficient to keep the bulb burning for a prolonged period. However, it is possible to operate this circuit from a mains driven power pack of the type that is sold at component stores.

In order to connect a battery eliminator into the circuit you will need to use a low voltage input connector socket, of the type suitable for the output from your power supply, which switches off the

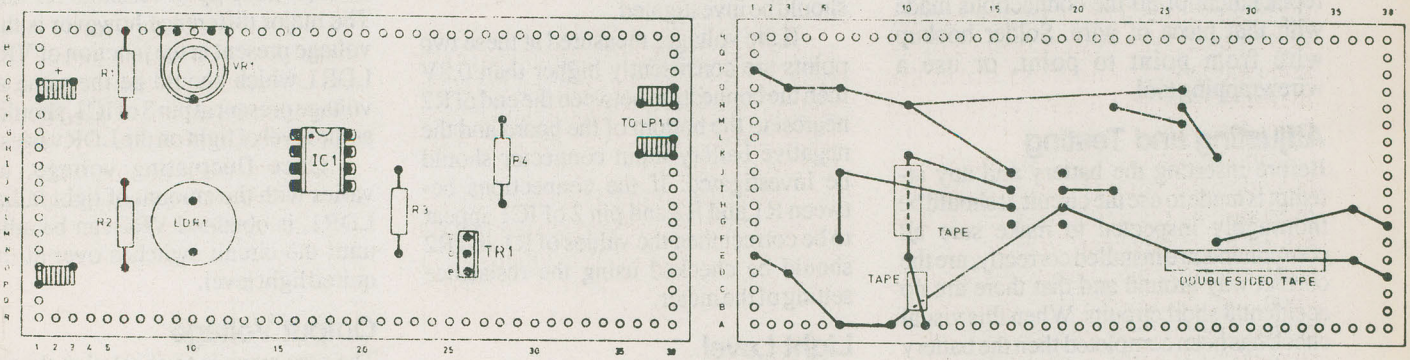


Fig. 3. Wiring for the Autolight circuit board.

internal battery when the external power supply is connected. This should be wired up as shown in Fig. 2.

Switching within the input socket SK1 works so that without the power plug inserted the contacts allow current from the battery to flow to the circuit in the normal way. When the power plug is inserted the internal switch mechanism disconnects the internal battery and powers the circuit from the circuit supplied by the power pack instead.

Under no circumstances should this project be connected to the mains EXCEPT through a SAFE low voltage power supply.

The on/off switch S1 is a simple, single pole, single throw switch which is included in the circuit so that it may be turned off when not required.

Construction

The layout of the components on the board together with the underside wiring is shown in Fig. 3. The components are simply inserted into the appropriate hole in the board from the side with the wider holes. When all of the components have been inserted into it, the board is turned over and the protruding component tails trimmed to a length of 3mm using a pair of side- cutters.

At this stage it is important to ensure that any polarity sensitive components are inserted into the board the correct way around. This should be double checked thoroughly before wiring the board up, since moving components after they have been wired tends to require the complete replacement of all the connections made with that piece of wire. Solder hookup wire from point to point, or use a wirewrapping tool.

Adjusting and Testing

Before inserting the battery and any attempt is made to use the circuit, it should be thoroughly inspected to make sure all components are installed correctly, are the correct way around and that there are no accidental short circuits. When this visual check has been completed then the battery may be inserted into its holder and switch S1 operated.

The first stage of the adjusting and testing procedure is to set the value of preset VR1 so that the lamp is turned on at the correct light level. To do this you should cover the LDR and adjust VR1 until the light comes on. If you then remove the covering and allow light to fall upon the LDR you should observe that the light is turned off. You can then adjust VR1 further until the bulb (LP1) switches on at the desired light level.

Fault Finding

Fault finding on this circuit can only really be accomplished by means of a multimeter. If the battery voltage is measured at the appropriate power points in the circuit and the circuit fails to work then it will be necessary to check the individual sections of the circuit.

Assuming that the battery voltage is available between pins 4 and 7 of IC1, the next stage is to check the voltages, with respect to the negative input to the board, at pins 2 and 3 of IC1. A voltage approximately 0.8V should be available at pin 2 and if this is not the case then the connections to the reference voltage divider, comprising resistors R1 and R2, should be checked.

With the meter, set to "volts", connected to the negative battery input the positive probe should be connected to the wire of R1 nearest to the top of the board. The battery voltage should be measurable at this point and if this is not the case then the connection between the positive power supply input and this point should be investigated.

The voltage at the other end of R1, at the junction with R2, should be approximately 0.8V. The voltage present at pin 2 of IC1 should also be checked and found to be the same as the voltage found at the junctions of R1 and R2. If this is not the case then the connection between the junction of R1 and R2 and pin 2 of IC1 should be investigated.

If the voltages measured at these two points are consistently higher than 0.8V then the connection between the end of R2 nearest to the bottom of the board and the negative battery input connector should be investigated. If the connections between R1 and R2 and pin 2 of IC1 appear to be correct then the values of R1 and R2 should be checked using the resistance setting of the meter.

Light Level

The next stage is to check that the light detecting circuit, consisting of VR1 and R3 (LDR) is operating correctly. The first stage is to check the voltage between pin 3 of IC1 and the negative battery input to the circuit board while varying the amount of light falling on the LDR.

The voltage at this point should vary according to the amount of light falling on the LDR. When very little light falls on the LDR then the voltage at pin 3 of IC1 should be between two volts and the battery voltage.

As the amount of light falling on it is increased by removing the shading between the source of the light and the LDR so the voltage at pin 3 should reduce to below the voltage measured at pin 2. If this is not the case then the connections in the vicinity of pin 3 of IC1 should be. If the voltage measures 0 volts, with respect to the negative supply voltage, then a check should be made between pin 3 and the positive battery input on the board.

If the battery voltage is measured between these two points then this would indicate either a wiring short circuit between pins 3, 4 or IC1 or a fault within IC1 itself. If no voltage is measured between either of the battery input connections and pin 3 then this would indicate that the fault lies with the interconnection between pin 3 of IC1 and the light sensing resistance chain (VR1/LDR1).

Another potential source of problems in the light sensing circuit is if VR1 is set so that there is very little resistance between the positive power supply rail and the connection of the wire of VR1 with the LDR then the variation of light levels on the LDR will have very little effect. A visual check should be made of the setting of VR1 and if necessary an adjustment of the setting VR1 made.

The potential divider circuit consisting of VR1 and LDR1 can be checked out in the same way as described for the checking of the fixed voltage potential divider made up of resistors R1 and R2. The major difference however is that the voltage present at the junction of VR1 and LDR1 which should be the same as the voltage present at pin 3 of IC1, should vary as the level of light on the LDR varies.

Once fluctuating voltage, which varies with the amount of light falling on LDR1, is obtained VR1 can be adjusted until the circuit switches over at the required light level.

Output Voltage

The next stage is to check that the output voltage of pin 6 of IC1 switches as the amount of light falling on the LDR is altered. With a voltmeter connected between the negative battery input to the board and pin 6 on IC1 the amount of light falling on the LDR should be varied by shading it with your hand.

When the amount of light falling on it is greater than the level at which you wish the circuit to switch then the output

measured between pin 6 of IC1 and 0 volts should be virtually 0. As the light falling on the LDR is reduced, by shading it with your hand, so the voltage set at pin 3 should rise above the voltage set at pin 2 and the output voltage at pin 6 should, at this stage, rapidly switch from 0 volts to virtually the battery voltage.

If this does not happen and you have already checked that the voltage at pin 3 fluctuates above and below the voltage of pin 2 then you should check that there are no short circuits associated with pin 6 of IC1. If the voltage present at pin 6 of IC1 is permanently at the battery supply voltage then a check should also be made to ensure that there is not an accidental short circuit between pins 6 and 7 of IC1.

If this reveals no fault, or if the voltage pin 6 remains locked at 0 volts, then a check should be made that the battery voltage is present across pins 7 and 4 of IC1. If all other checks reveal nothing to be wrong then it must be suspected that IC1 is faulty and it should be replaced with a new one.

Output Circuit

Fault finding on the output circuit is relatively simple. The first stage is to check that bulb LP1 is firmly screwed into its lamp holder and that the connections are correctly made to the connectors on the board.

Once this has been done the next stage is to make a *temporary* short between the emitter and collector of transistor TR1. This should cause LP1 to light up. If LP1 does not illuminate when tested in this way then a careful check should be made of the lamp circuit from the battery positive connection to the board, through the under-board wiring to the positive side of LP1 and from LP1 through resistor R5 and the collector and emitter of TR1 to the negative battery connection. A break of any description along this chain will cause the lamp not to illuminate.

If the lamp illuminates when tested in this way when the short circuit between the collector and the emitter of TR1 should be removed and the voltage between the negative battery connector and the base of TR1 should be checked. When battery voltage is applied to the end of R4 which is connected to pin 6 of IC1 then approximately 0.7 volts should be measured between the base and emitter of TR1. This should cause LP1 to illuminate.

If no voltage is measurable between the base and emitter of TR1 when battery voltage is available at pin 6 of IC1 then the voltage present at the end of R3 nearest to the top of the board should also be measured. If the battery voltage is not present here but is present at pin 6 of IC1 then the connection between pin 6 IC1 and R3 should be investigated. If battery voltage is measurable at both ends of R3 then the connection between R3 and the base of TR1 should be investigated.

If all of the foregoing checks prove that there is nothing wrong on the circuit board then the voltage present between the emitter and the base of TR1 should be measured. If 0.7V or more is present at this point and the transistor still fails to cause LP1 to illuminate then it must be suspected that TR1 is defective and should be replaced.

Case

Before the project can be installed into a case a suitable sized case should be prepared. It is important to realize that the case layout should be designed so that the light from bulb LP1 does not shine onto the LDR and that the circuit board can be installed with the LDR exposed to the ambient light through a hole in the case.

In the prototype it was decided that LP1 would be mounted so as to protrude through the top of the case with the LDR mounted in what is effectively the front of the case (which is in fact the bottom of the case) furthest away from the removable lid. When suitable positions for these components and also for S1 and, if used, the input power supply jack socket JK1 have been formed the case should be carefully drilled with holes of the appropriate sizes to accommodate these components.

Because it is potentially difficult to assess the correct position of the LDR by holding the circuit board up to the case it will be necessary to find a position for the LDR by careful measurement. Once the hole to accommodate the LDR has been drilled in the case then the circuit board may be offered up to the case wall and the LDR accurately positioned.

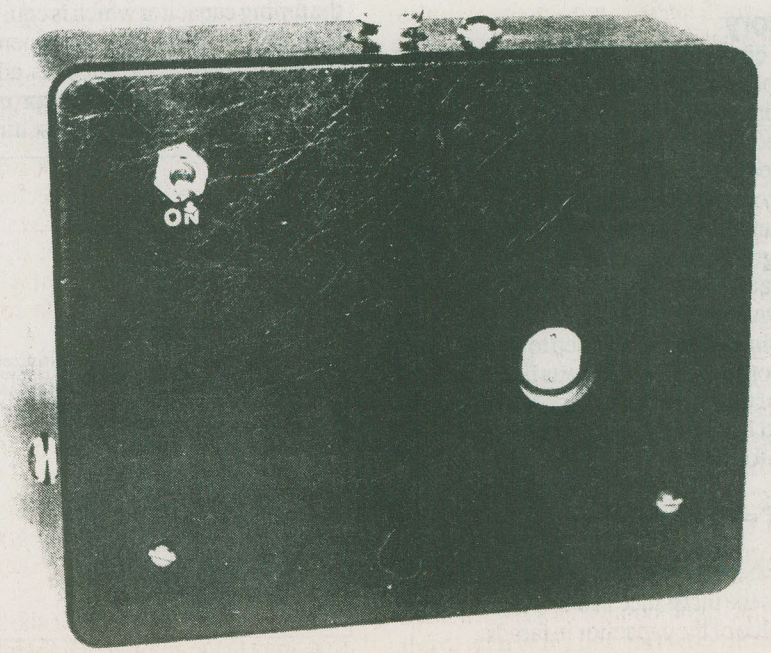
In order to allow the LDR to be mounted as close as possible to the body of the case it will be necessary to carefully bend the body of transistor TR1 over so as to make it as close to the component board as possible. The mounting holes for the circuit board can then be marked and drilled.

Once these holes have been drilled and their edges cleaned up any lettering you may wish to use on the case may be applied.

In Use

This project is very simple to use. All that it is necessary to do is to set VR1 to give precisely the correct switching point and then turn the unit on.

It must be remembered that even when the lamp is not illuminated a current is being drawn from the battery, so when the unit is not required to be in use it should be turned off to conserve battery life. ■



PROJECT

Game Timer

Speed up the moves with this easy-to-build timer.

Chris Bowes

When playing a game where one person has to make a move at a time, disputes sometimes arise because one player seems to take very much longer than other players. This timer has been designed to indicate that a set time has expired by sounding a buzzer.

Theory

This circuit uses the 555 timer IC, but in this project it is used in a different mode than is usually found. This time the circuit is used in the monostable mode with the IC connected as in Fig. 1. In this mode the output from the integrated circuit is in the Off state until the circuit is triggered by a negative-going pulse applied to pin 2. Immediately, the output from the IC goes to the On state and remains there (provided that pin 2 has been returned to a state where it is not connected to 0 volts before the expiry of the timed period) for a period determined by the values of R and C according to the formula:

$$T = 1.1 \times R \times C$$

where T equals the time in seconds, R equals the resistance in ohms and C equals the value of the capacitor in farads.

Circuit Description

The circuit diagram for the Game Timer is shown in Fig. 2. VR1 and R1 form the timing resistor which is equivalent to R in Fig. 1. The inclusion of VR1 in series with R1 allows the circuit to be adjusted so that timings of different length can be set. C1 is the timing capacitor which is equivalent to C in Fig. 1. With the component values shown in Fig. 2, the timer is adjustable from a minimum setting of approximately ten seconds and a maximum setting of approximately one minute.

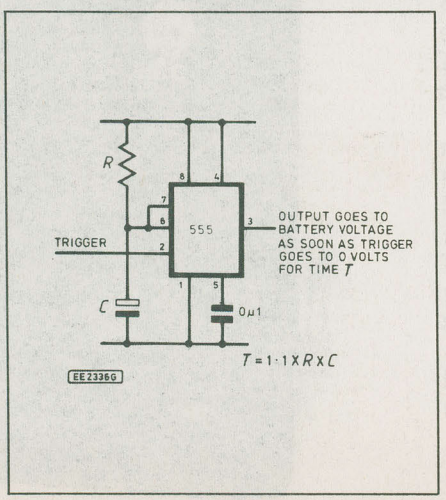


Fig. 1. Basic 555 timer circuit.

Components

R2 and C2 form a negative pulse-generating circuit which is used to trigger the integrated circuit as soon as power is applied to the circuit when S1 is closed. When the circuit is first turned on, C2 is discharged, which causes the voltage at pin 2 to be at ground potential (0 volts). As soon as the circuit is switched on, current from the battery flows through R2 to C2, causing the

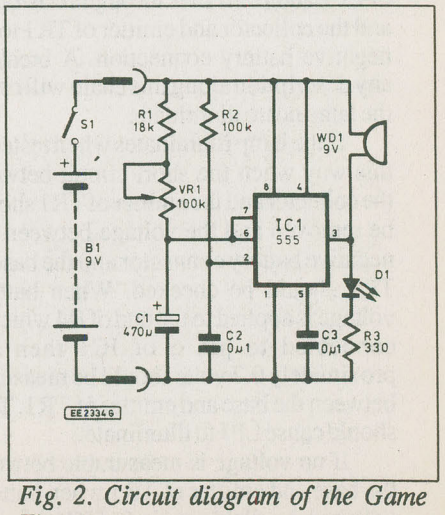


Fig. 2. Circuit diagram of the Game Timer.

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Game Timer

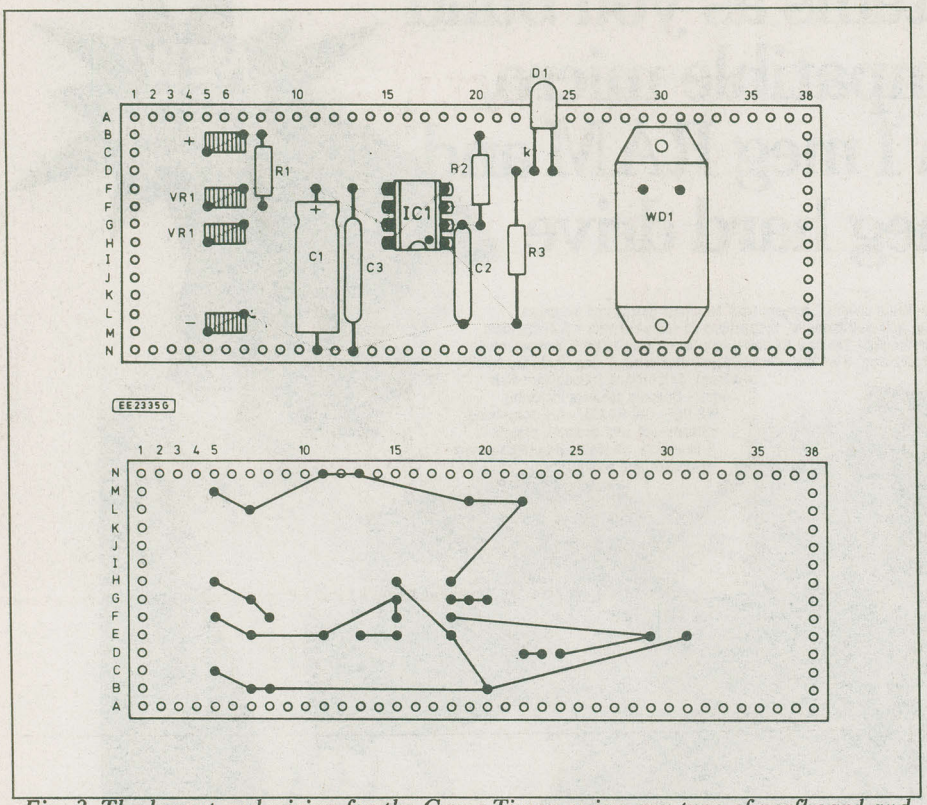

Fig. 3. The layout and wiring for the Game Timer, using any type of perfboard and point-to-point hookup wire underneath.

capacitor to rapidly charge, and thus bringing the voltage at pin 2 to the power supply voltage. This causes a very short negative-going pulse to be applied to pin 2 which is sufficient to trigger the circuit, but also ensures that the voltage at pin 2 has risen above 0 volts before the circuit times out. C3 is a decoupling capacitor connected between the ground rail and pin 5 of the IC in order to set the control voltage of the circuit to its optimum value.

As soon as IC1 has been triggered, the output voltage at pin 3 goes to the battery voltage. This in effect shorts out WD1 and causes a current to flow through D1 via R3. This causes the LED to glow; R3 restricts the LED current to a safe level. When the circuit times out at the end of the timing period set by VR1, R1 and C1, the output voltage at pin 3 falls to 0 volts. This effectively shorts out the LED, but allows a current to flow through WD1, which sounds.

Switch S1 is a standard on/off switch which controls the power as required. The circuit is designed to run from a standard 9V battery, shown as B1 in the circuit diagram.

Construction

This project has been designed to be constructed using any type of perforated board. The first step is to obtain a board with at least 38 by 14 holes. Insert the components into the board according to Fig. 3, observing polarity for components such as IC1, C1 and D1. Turn the board over and trim the leads to a length of about 1/8" (3mm).

Now you can connect the points together as shown at the bottom of Fig. 3, using either hookup wire and soldering, or a commercial wirewrap tool.

Before testing or installing the battery, check for wiring errors or components that have been inserted with the wrong polarity.

Testing and Troubleshooting

Before the circuit can be installed into its case, it should be tested to ensure that it works as described in the circuit description.

If the circuit does not work correctly, it will be necessary to check logically through the circuit. The first step is to repeat the visual checks on the circuit to ensure that it actually conforms to the diagram and that, where required, the polarity of the components is correct.

If a visual check produces no indication of what the fault may be, then the battery should be checked with a voltmeter to ensure that it's providing adequate output both when connected and disconnected. If the voltage is low when disconnected, the battery should be replaced. If the voltage is correct when disconnected but falls considerably when connected, the most likely cause is a either a wiring fault, causing a short circuit between the supply rails, or connection of a polarity- sensitive component the wrong way around.

The first stage of circuit testing is to check out the circuitry associated with IC1; check that the battery voltage is measurable between pins 1 and pins 8 and 4 of the IC. If these checks do not reveal the presence of the battery voltage, then the connections between these points and the battery should be checked for continuity with the test meter. All of the connections to IC1 should also be carefully checked for errors and short circuits.

The next stage is to check that a voltage of about 2/3 of the battery supply voltage can be measured between pins 1 and 5 of IC1. If this voltage cannot be measured, then the connections to and through C3 should be checked.

Next check that the circuit through R1 and VR1 to pins 6 and 7 of IC1 is correctly made, remembering that these connections also pass through the connectors on the board and the wires connecting them to VR1. If these connections are correct, then the voltage across C1 should be seen to rise steadily to the same voltage as that across C3 when the circuit is turned on. If this doesn't happen, then a temporary short circuit should be made between pins 1 and 2 of IC1 to see if this starts the circuit operating. If this technique does cause the circuit to start, then the connections associated with R2, C2 and pin 2 of IC1 should be checked.

If a rising voltage can be measured across C1, then the voltage at the output (pin 3) should switch from 0 volts to the battery voltage as soon as the circuit is switched on and should drop to 0 volts as soon as the voltage measured at pins 6 and 7 rises to about 2/3 of the battery voltage. If this doesn't happen, then the connections associated with pin 3 of the IC should be checked to ensure that there are no wiring errors or short circuits to either of the supply rails.

If the output of the IC switches between 0 volts and the battery voltage correctly, but the output devices do not operate properly, then the connections between pin 3 and the devices should be checked, as well as the polarity of D1 and WD1.

The most likely causes of the LED not

working are either that it has been inserted incorrectly, or there is a poor connection between the LED and R3. If necessary the output components can be tested directly by shorting the connection to pin 3 to the opposite power rail to which the suspect component is connected. If this course is taken, it is suggested that IC1 be removed from the circuit before this is done.

Case Mounting

Once the project has been tested, it can be mounted in the case of your choice. Some small utility boxes have grooves in the side for holding circuit boards, and the board can often be cut to fit these. D1 should protrude through a hole in the front panel, and it can be extended with a pair of wires if necessary. Mount potentiometer VR1 in a suitable hole in the front panel. The battery can be secured with foam (such as self-adhesive foam weatherstripping) or you can use a proper plastic or metal battery holder.

In Use

To use the circuit it is necessary to set VR1 to an appropriate setting and operate S1. At this point D1 should light and the buzzer shouldn't sound. After the timing period has elapsed, the LED should go out and the buzzer should sound until the timer is switched off.

Parts List

Resistors

R1 ..... 18k
R2 ..... 100k
R3 330
All 1/4w, 5%

Capacitors

C1 ..... 470u 10V
C2,3 ..... 0.1u

Potentiometer

VR1 ..... 100k linear

Semiconductors

D1 ..... red LED
IC1 ..... 555 timer

Miscellaneous

S1 ..... SPST switch
B1 ..... 9V battery, connector
WD1 ..... 9V buzzer

Perfboard, wire, case to suit, knob for VR1.

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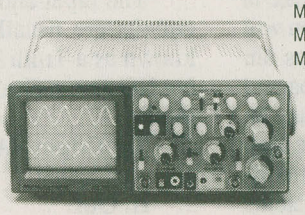

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PROJECT

Possession Loop Alarm

Guard your possessions with this inexpensive loop alarm.

Chris Bowes

This circuit is designed to operate in the same way as the alarms you will find in stores, where valuable items are linked together by a wire which is passed through the items and which causes an alarm to go off if the continuity of the loop is broken. Although this circuit is not as invincible as the more sophisticated systems found in the stores, it should provide sufficient security to prevent casual removal of items by the opportunist.

Theory

The heart of the circuit is a latch made up of two 2-input NAND gates in a "cross coupled" configuration. Logic circuits are so called because they have built into them a "logic" which decides what state the output of the device will be for all of the possible combinations of input conditions. Unlike other types of circuit, logic circuits operate with only two input/output voltage conditions. These are the logic "1" state which is the same as whatever the battery voltage happens to be, in other words an "On" state, or the logic "0" state which is 0 volts or an "Off" state.

The input and output states of logic circuits are usually shown in a format known as a Truth Table. For a two input NAND gate such as the ones we are using this is:

Two Input NAND Gate

In		Out
0	0	1
0	1	1
1	0	1
1	1	0

This may look slightly complicated but what is really shown is that the output of the NAND gate is in the logic 1 (on) state except for the one combination when both of the inputs are in the logic 0 (off) state.

In this circuit two 2-input NAND gates are connected into a cross coupled arrangement which makes the circuit operate so that when the available input to one gate is made to go briefly to the logic 0 state (0 volts) then the latch is triggered, going to the logic 1 state, and will remain in that state until the spare input to the other latch is made to go to the logic 0 state. The characteristic of this cross coupled gate circuit is that the two gates operate so that when the output of one of the gates is at logic 0 the output of the other gate is at the logic 1 state.

In the circuit used for this project the spare input to one of the cross coupled gates is held in the logic 1 state by being connected to the battery positive supply rail through the alarm linking wire. If this connection is broken the spare input is pulled down to the logic 0 state, by a "pull down" resistor connected to the 0 volt rail. Thus breaking this connection by attempting to remove a protected article causes the input to the gate to fall to the logic 0 state which immediately triggers the alarm.

The other input to the cross coupled gates is a circuit which provides a very short, negative pulse. This circuit automatically sets the latch to the correct state, as soon as power is applied to the circuit.

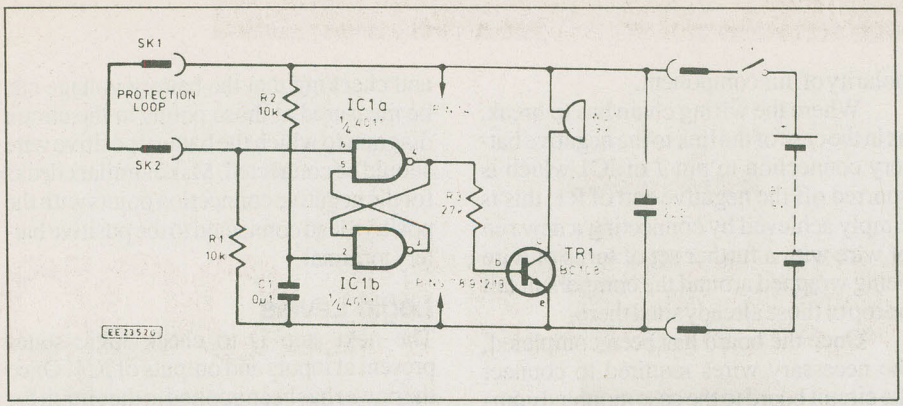


Fig. 1. Circuit diagram of the Possession Loop Alarm.

The output from the latch circuit is of a relatively low current handling capacity so the alarm is actually switched off and on by a simple transistor switch.

Circuit Description

The circuit diagram for the project is shown in Fig. 1. The latch circuit is made up of the two NAND gates IC1a, IC1b, which are each one quarter of a 4011, quad, 2-input, NAND gate. The other two NAND gates available in the 4011 integrated circuit are not used and, in order to prevent them from interfering with the operation of the circuit, their inputs are connected to 0 volts.

Resistor R1 is a pull down resistor which is attached to the input of IC1a which is not cross coupled with the output of IC1b. This input is held in the logic 1 state by being connected, through the protection link, to the positive battery voltage via the two sockets SK1 and SK2. As long as a sound connection exists between SK1 and SK2 then this input is held at the logic 1 state and the latch remains in the untriggered state.

As soon as the link through the protected possessions is broken then the state of this input falls to the logic 0 state, by virtue of it being connected to 0 volts via R1. This causes the circuit to trigger, with the outputs of IC1a and IC1b switching states so that the output of IC1a goes to the logic 1 state.

Resistor R2 and capacitor C1 form a negative pulse trigger circuit which is connected to the input of IC1b so as to reset the latch as soon as power is supplied to the circuit. Initially, with the power supply to the circuit switched off, C1 is discharged. This causes the input to IC1b to be in the logic 0 state immediately the circuit is switched on. However, as soon as power is supplied to the circuit, C1 starts to charge rapidly through R2. This causes the input to IC1b to rise to the logic 1 state. The effect of this is to cause the output of IC1a to go to the logic 0 state immediately the circuit is switched on and to remain in that state until triggered by the breaking of the circuit between SK1 and SK2.

The output from the logic circuit is capable of handling only a relatively small output current and, in order to ensure reliable operation of a loud alarm buzzer, a simple transistor switching circuit comprising TR1 and R3 is used. When a cur-

Parts List

Resistors

R1,2 .....10k
R3 .....27k
All 1/4 watt 5%.

Capacitors

C1 .....0.1u
C2 .....2u2 tantalum 10V

Semiconductors

TR1 .....2N3904, BC108, etc
IC1 4011.....2-input NAND gate

Miscellaneous

S1 SPST key operated switch
SK1, SK2 single connection sockets (see text)
B1 9V battery plus connector
WD1 audible warning device, 9V operation

Perfboard, wire, case to suit.

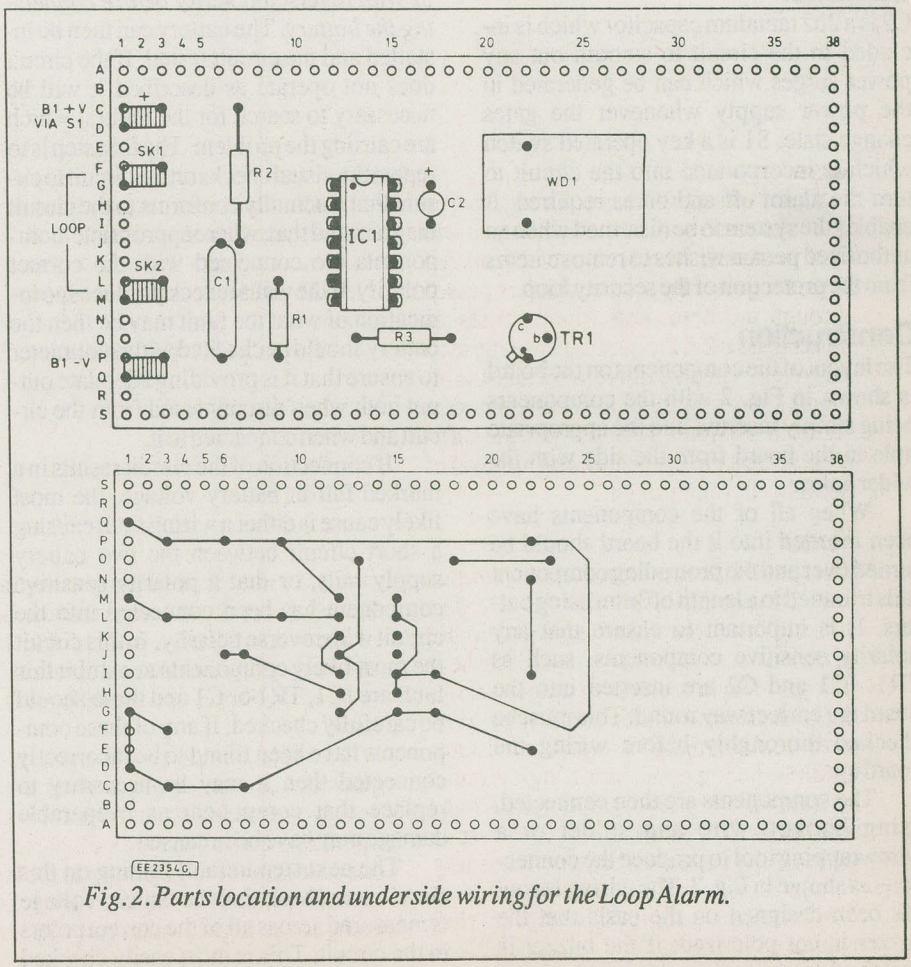


Fig. 2. Parts location and underside wiring for the Loop Alarm.

rent is allowed to flow through the base/emitter connection of a transistor it allows a much larger current to be drawn through the emitter/collector circuit. In the case of the transistor chosen the current which may be drawn through the collector/emitter circuit is approximately 150 to 200 times the current which is required to flow through the base/emitter junction in order to switch the transistor on.

A current flows through the base emitter junction as soon as the voltage between the base and emitter exceeds 0.7 volts. As the logic 1 state of the output from IC1a is equivalent to a voltage of 9 volts, R3 is included in series with the base TR1 so as to prevent a voltage in excess of 0.7 volts appearing across the base/emitter junction. If R3 were not included in the base circuit of TR1 then the action of the transistor would be to attempt to reduce the battery voltage to 0.7 volts, by dissipating the excess voltage as heat. This would cause failure of the transistor.

Capacitor

C2 is a 2u2 tantalum capacitor which is included in the circuit to smooth out any power surges which can be generated in the power supply whenever the gates change state. S1 is a key operated switch which is incorporated into the circuit to turn the alarm off and on as required. It enables the system to be disarmed when an authorized person wishes to remove items from the protection of the security loop.

Construction

The layout of the components on the board is shown in Fig. 2 with the components being simply inserted into the appropriate hole in the board from the side with the wider holes.

When all of the components have been inserted into it the board should be turned over and the protruding component tails trimmed to a length of 3mm using cutters. It is important to ensure that any polarity sensitive components, such as TR1, IC1 and C2 are inserted into the board the correct way round. This must be checked thoroughly before wiring the board up.

The components are then connected, using hookup wire and solder or a wirewrapping tool to produce the connections as shown in Fig. 3. The wiring layout has been designed on the basis that the buzzer is not polarized; if the buzzer is polarized then the wiring layout may have to be redesigned to accommodate the polarity of this component.

Where the wiring chain has to break, as in the case of the link to the negative battery connection to pin 7 of IC1 which is spurred off the negative end of R1, this is simply achieved by connecting a new run of wire with a further set of turns of wire being wrapped around the component tail on top of those already sited there.

Once the board has been completed, the necessary wires required to connect the circuit board to the case mounted components (S1, SK1 and SK2) can be prepared with the correct terminations to mate up with the on-board connectors. In the case of the end of the wire which is connected to the board this is a simple matter of crimping on the connectors with pliers to the bared end of the wire. The other ends of the wire will, however, need to be soldered onto the components.

Testing and Fault Finding

Before proceeding any further it is necessary to visually check for short circuits or components installed in the wrong places or with reversed polarity *before connecting the battery*. The battery can then be installed and the circuit tested. If the circuit does not operate as described it will be necessary to search for the fault(s) which are causing the problem. The first step is to repeat the visual checks on the circuit to ensure that it actually conforms to the circuit diagram and that, where appropriate, components are connected with the correct polarity. If the visual check produces no indication of what the fault may be then the battery should be checked with a voltmeter to ensure that it is providing adequate output both when disconnected from the circuit and when connected to it.

If connection of the circuit results in a marked fall in battery voltage, the most likely cause is either a wiring fault causing a short circuit between the two battery supply rails, or that a polarity sensitive component has been connected into the circuit with reverse polarity. In this circuit the most likely components to exhibit this fault are IC1, TR1 or C1 and these should be carefully checked. If any of these components have been found to be incorrectly connected then it may be necessary to replace that component as irreparable damage may have been caused.

The next step in fault finding on this circuit is to check that the battery voltage is measured across all of the correct points in the circuit. This is most easily checked by connecting the negative lead of the voltmeter to the negative input connection and checking that the battery voltage can be measured at those points in the circuit diagram to which the battery positive wire should be connected. Make similar checks for the negative connection points with the positive lead connected to the positive battery terminal.

Logic Levels

The next step is to check logic states present at inputs and outputs of IC1. Once the power has been applied to the circuit for long enough for C1 to charge then pin 2 of IC1 should be a the logic 1 (9V) state. If this point is found to be at the logic 0 (0V) state then the most likely causes are: a short circuit in or across C1; a poor connection between the positive power supply rail and the positive end of R2; a poor or missing connection between the negative end of R2 and the positive end of C1; or a poor or missing connection between the junction of R2 and C1 with pin 2 of IC1.

A similar check should be carried out on the logic state at pin 6 of IC1. With a sound connection between SK1 and SK2 the state of pin 6 should be at logic 1 but this should fall to the logic 0 state when the link between SK1 and SK2 is removed. If this does not happen then the connections between SK1 and the positive power supply rail and those between SK2, R1 and pin 6 of IC1 should be checked, as should the voltage present at the negative end of R1, which should remain at 0 volts in all circumstances.

The output states of the two gates at pins 3 and 4 of IC1 should also be checked. These two pins should always be at opposite logic states with pin 4 being at logic 0 if the circuit is switched on with the protective link intact and going to the logic 1 state as soon as the connection between SK1 and SK2 is broken. If this does not occur then the connections between pins 3 and 5 and between pins 1 and 4 of IC1 should be checked. Pins 7, 8, 9, 12 and 13 of IC1 should also be checked to ensure that they are at the logic 0 state.

If the logic states of the inputs are correct but the logic states of the output are not then a check for short circuits across or between pins 3 and 4 and their neighbours should be made. If no problem is found with these connections then it is most probable that the IC is faulty and it should be replaced.

Buzzer

If the output states of IC1 check out correctly but the buzzer does not sound when pin 6 of IC1 is in the logic 1 state then the

transistor output circuit should be checked. To test the buzzer it is necessary to briefly short out the emitter and collector of TR1 which should cause the buzzer to sound. If this does not occur then the connections from the positive power supply rail through the buzzer to the collector of TR1 and between the emitter of TR1 and the negative power supply rail should be checked. If these connections are sound and the polarity of the buzzer (if any) is correct but the buzzer does not sound then the buzzer should be removed from the circuit and tested independently across the disconnected battery.

If the buzzer sounds when the emitter and collector of TR1 are shorted out but does not sound when the output of IC1a goes to the logic 1 state, then the connections between pin 4 of IC1 and the base of TR1 through R3 should be checked to ensure that they are sound. When the output of IC1a is in the logic 1 state, the battery voltage (measured with respect to the negative power supply connection) should be measurable at the top of R3 and approximately 0.7 volts should be measurable both at the negative end of R3 and at the base of TR1.

If no voltage is measurable at the base of TR1, but the battery voltage is measured at the end of R3 which is connected to pin 4 of IC1, then the resistance of R3 should be measured to make sure that it is correct. If all is correct but either no voltage is measurable between the base and emitter, or a voltage of 0.7 volts or more is measurable between the base and emitter of TR1, but the buzzer does not sound then it may be assumed that TR1 is faulty and should be replaced.

Housing

This circuit must be enclosed in a case in order to prevent unauthorized tampering which might destroy its effectiveness. Ideally the switch S1 should be mounted in an easily accessible position with the sockets SK1 and SK2 similarly mounted where the wire protection loop may be easily disconnected or connected by an authorized person. It is, however, important when selecting SK1 and SK2 to ensure that it is not possible for SK1 and SK2 to be shorted out without the unit being turned off.

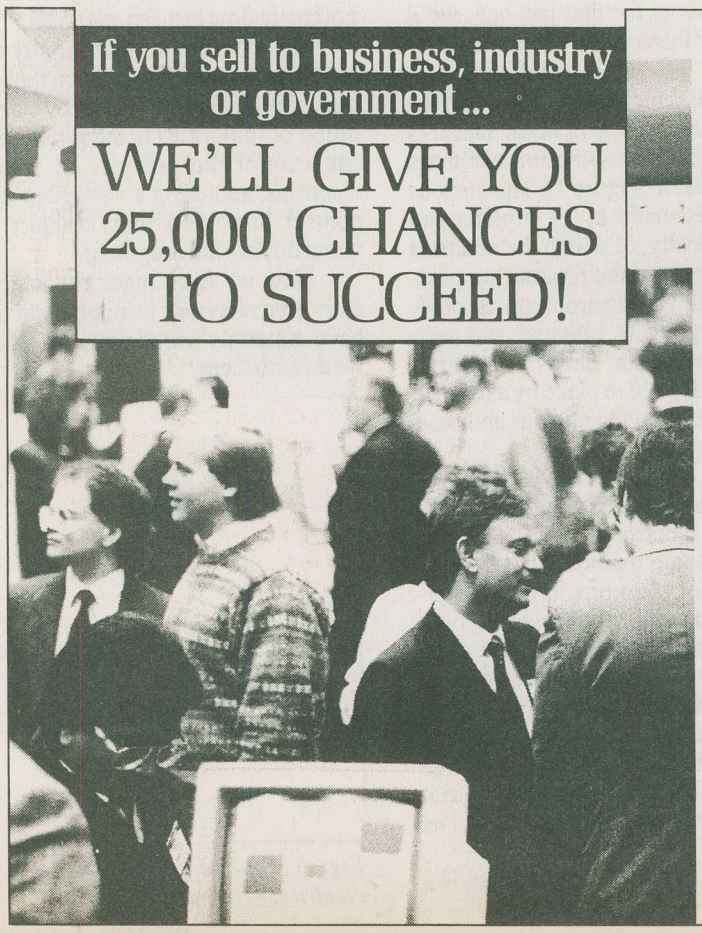
Once a suitable case has been obtained then the necessary holes must be made to mount SK1, SK2 and S1. It will also be necessary to consider how the case can be securely attached to a suitable surface so that it may not be removed along with the possession it is intended to protect. If necessary drill suitable mounting holes in the case.

Once the enclosure has been prepared then the case mounted components can be installed along with the circuit board and the case mounted components connected to the board. The circuit should be tested once more to ensure correct operation before the lid is screwed shut and the alarm used in earnest.

In Use

To use the Possession Alarm it is necessary to securely fix the device to a suitably immovable part of the building or a heavy piece of furniture close to the articles you wish to protect. A single conductor wire is then connected between SK1 and SK2, threaded through holes in the devices or equipment that you wish to protect.

Once the loop of wire is in place, the key switch can be turned on. As long as the connection between SK1 and SK2 remains intact the alarm will not sound. As soon as the circuit is broken then the buzzer will sound and remain on until either the battery wears out or the alarm is switched off by turning the key switch. ■



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PROJECT

Basic Electricity Part 1

A new series covering the theory and practice of the basics.

Ron C. Johnson

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If so, this series on basic electricity and electronics will serve to fill in the blanks in your knowledge. If you are already familiar with some areas they can be a review to sharpen your skills.

Electronics, like other areas of applied science, is heavily reliant on mathematics in dealing with the relationships involved. In this series we will attempt to minimize the amount of mathematics and give an overview of the subject in a qualitative way. Unfortunately, for those of us who do not get a thrill out of number crunching, we will not be able to avoid it altogether. Hopefully, we can sneak it in a little at a time in a way that supports the concepts without forcing us to become human calculators.

Back to the Basics

Those of you who have had high school physics and chemistry can now drag out your old text books and blow the dust off them. We are going to enter the sub-atomic world to look around at the nature of charged particles.

Don't worry, it won't hurt a bit.

Why do we call copper, nickel, gold, etc., *conductors* while other materials are called *insulators*? What is a *semi*conductor anyway? What makes current flow in a conductor and what really is *current*? Why is the sky blue?

Well, except for that last one, we'll try to answer these and a few other questions here.

If you are somewhat familiar with the structure of the atom you know that it is made up of a nucleus with some electrons orbiting around it (Figure 1). The nucleus of an atom is made up of protons and neutrons basically, of which the neutrons have no charge and the protons are positively charged. The electrons, on the other hand, are negatively charged and spin around the nucleus in "shells", or energy levels. They are held in place by a balance of their attraction to the nucleus and their centrifugal force.

All the elements have different atomic structures with varying numbers of protons and electrons. It so happens, though, that some materials have an incomplete set of electrons in their outermost shell. This makes the remaining ones easier to remove by adding a little extra energy to that material (heat or some other force). Add that energy and "presto" we have free electrons floating around in the material. A material which has lots of free electrons is called a *conductor* because it can easily carry the flow of electrons through it.

An *insulator*, on the other hand, is a material in which the atomic structure is very stable. Because the outermost shells in these materials are filled with the correct number of electrons it would take considerable force to remove any electrons from their orbits. Therefore current will not easily flow in these materials.

Semiconductors are initially similar to insulators in that they have their outermost shells filled. However, by careful addition of impurities to these materials we can control the presence of some free electrons, and using a voltage or current, control how well they conduct. More about this in a later segment.

Now we have materials which will carry free electrons through them and we have materials which will not. What can we do with them?

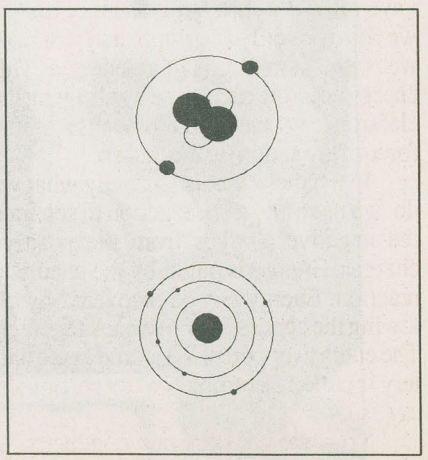

Fig. 1. Typical atomic structure with electrons orbiting the nucleus.

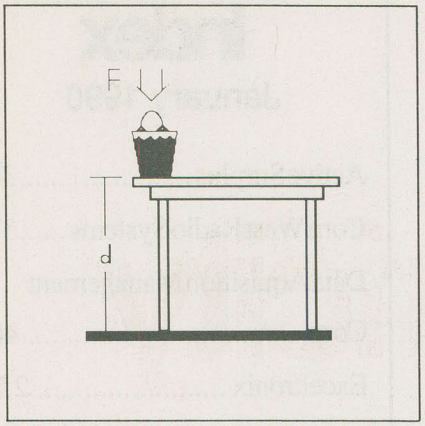

Fig. 2. Potential energy is stored by lifting the pail from floor to table.

Let's look further into the matter.

Work and Energy

In asking what can we do with them, what we are really asking is: How can we do some work with these materials?

If you remember your high school physics you will recall that work is accomplished if you move a force through a distance. You can build up potential energy (stored work) if you put energy into a system. For example, if you lift a pail of water from the floor and place it on a table you have operated a force (against gravity) through a distance (from floor to table) (Figure 2). Once there, it has stored potential energy which can be recovered by lowering the pail back to the floor. What has that got to do with electricity?

Well, think about the charges in the atoms we talked about earlier. We know that the negative electrons are attracted to the positive protons. That attraction is a *force*. If we move the electron farther away from the proton it will require a force against the attraction to do so. We will have moved it through a distance and so we have not only accomplished work but we have stored potential energy. This energy could be recovered by allowing the electron to travel back (because of the force of attraction) to the proton.

In a battery that is basically what we do: we use a chemical reaction to separate the negative charges from the positive charges. Energy is put in by the chemical reaction. Energy can be recovered by allowing the charges to move back together. The energy (or potential) stored in the battery is called electromotive force, or *voltage*.

Now we connect our conductor, a copper wire, between the two connections on a battery (Figure 3). The chemical reaction in the battery has produced a potential which causes electrons to flow through the wire to the other post of the battery. (The post which has the abundance of negative charges is called the negative post, while the post which has the abundance of positive charges is the positive post.) We notice that the copper wire becomes very hot and even starts to glow. Why should this be happening?

The fact is that even copper, an excellent conductor, is not a perfect conductor. As the electrons are pushed along the wire by the electromotive force they have a tendency to bump into atoms and other free electrons. As they do so, some of the energy used to move them through the wire is converted into heat energy and light energy. The extent to which a conductor opposes the flow of electrons is called *resistance* and is determined by the kind of material, its length, and cross-sectional area. The rate of the flow of electrons (charge per second) is called the *current*.

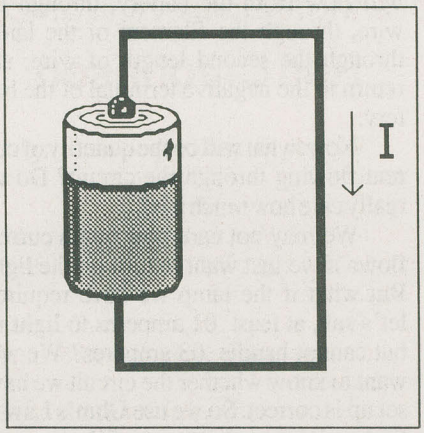

Fig. 3. A typical D cell with current flowing through the conductor connecting the terminals.

Now the confusion. Even though we know that it is the electrons which flow through the wire (because they are the mobile charge and a much lower mass than protons), in electronics it is conventional to think of current as flowing from the positive terminal of a battery or other power source, to the negative terminal. This is called *conventional current flow* and is more rooted in history than in physics.

So now we have electromotive force, or voltage, current, and resistance. How do these actually relate?

Ohm Sweet Ohm

Here is where we will sneak in a little math. The relationship between voltage, current and resistance is called *Ohm's Law*, and is expressed as follows:

$$E = I \times R$$

where E is electromotive force or voltage in volts, I is current in amperes, and R is resistance in ohms.

(Note that when we talk about electromotive force or voltage supplied by a battery or power source the symbol is E, whereas when we talk about a voltage drop across a resistance we symbolize voltage with V.)

Ohm's Law is the basic mathematical building block of electricity and as such is something we need to remember to understand what is going in electrical and electronic circuits. Let's use an analogy to help understand the relationships here.

Remember we talked about lifting the pail of water to the top of a table and in so doing storing energy there (Figure 4). The potential energy in that pail of water is like voltage. There is a force, created by gravity, which is exerted on the water. At this point the water cannot go anywhere. Now let's put a valve into the side of the pail near the bottom and another pail on the floor below it (no need to be sloppy here). When we open the valve part way the water runs out of the top pail into the bottom pail at a rate determined by how much we have opened the valve. The restriction of the valve is analogous to resistance. The rate of the flow of the water is similar to current (which is the rate of flow of charged particles or electrons). We will see in future issues how the pail at the bottom can be compared to a capacitor storing charge.

The difference between the water analogy and electricity is that in electric circuits we have just that — *circuits*, or

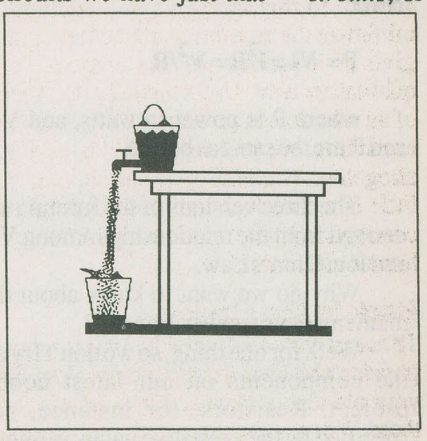

Fig. 4. Water pressure (due to potential energy forces water to flow. The valve restricts the rate of flow.

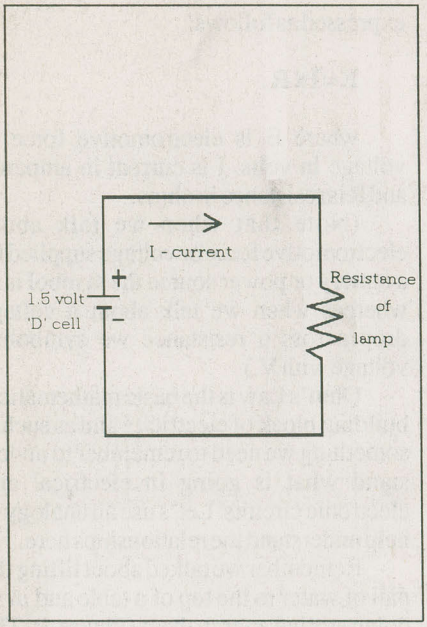

Fig. 5. A simple electrical circuit.

circles. Current always flows in complete loops from the positive terminal of the power source, through a resistance or energy converter of some kind, back to the negative terminal of the source. (Remember we are talking about conventional current flow.)

Power

The other mathematical relationship we should look at in this issue is *power*. We said that in connecting our copper wire from the positive post to the negative post of the battery that current flowed and the wire became hot and glowed. In doing so we have converted electrical energy into thermal energy and radiant energy dissipating power in the process. We can determine the power dissipated by the formula:

$$P = VI = I^2R = V^2/R$$

where P is power in watts, and V, I and R are the same as before.

The three versions of the formula are derived from the relationships among V, I and R in Ohm's Law.

Why do we want to know about the mathematics of power, you say?

Well, for one thing, so we don't fry all the components on our latest hobby project. Resistors, for instance, are specified by their resistive value, in ohms, but also have a maximum power they can dissipate before they go up in smoke. We have to be able to tell if we are subjecting them to too much voltage and current unless we plan on making toast out of our projects.

The Real Thing

Finally, let's put this all together in an actual electric circuit and see how it works. In fact, if you want you can set this up and check it out yourself.

In Figure 5 we have a simple electric circuit consisting of a battery (the power source), and incandescent lamp (the resistance, or energy converter), and wire connecting them (the current path). The battery we are using is a standard D cell (used in flashlights, etc.) which has electromotive force of 1.5 volts. The incandescent lamp has an internal filament resistance of 100 ohms.

As the circuit is constructed current will flow from the battery, through the wire, through the filament of the lamp, through the second length of wire, and return to the negative terminal of the battery.

Now, what will be the quantity of current flowing through the circuit? Do we really care how much it is?

We may not care how much current flows if we just want to turn on the light. But what if the lamp we have requires, let's say, at least .01 amperes to light up but cannot handle .03 amperes? We will want to know whether the circuit we have set up is correct. So we use Ohm's Law to find out how much current will be present:

$$V = I \times R$$

so I = V/R = 1.5 volts/ 100 ohms = .015 amperes

This is within the range specified so the circuit will work properly.

We can also determine how much power the circuit is dissipating by using the power formula:

$$P = V \times I$$

= 1.5 volts x .015 amperes = .0225 watts

These are the basic, but vital, aspects of electric circuits. Everything else builds from here. And it gets more practical and interesting.

Next month we will take a look at series and parallel circuits, switches and fuses, power sources, and lots of other interesting things.

Hope you'll get a charge out of it. ■

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ALMOST FREE SOFTWARE

VOLUME FIFTY-SIX

This month's Almost Free Software collection has been crafted with winter in mind. If it's too cold to go outside, there's nothing better than a few games to kill time. This collection has several superb ones.

It also has some first class DOS utilities and a really great dBase file browser.

Every program in this collection has been extensively checked to make sure that it functions as it should and that it contains no viruses or other nasties. Most sources of public domain software do not provide you with this assurance.

This collection carries the same promise that all our Almost Free Software does. If you don't feel that it's fair value once you've checked it out, we'll buy it back from you with no gripes or questions.

If you have problems with it, our help desk is as near as your phone... just call (416) 445-5600.

Please note that this is a two disk set which will unpack onto four floppies worth of software, about 1.4 megabytes in all. The slight increase over our usual $19.95 price is to offset the cost of the second disk.

MEMORY is a Windows program which will show you how much DOS, extended and expanded memory Windows thinks you have free.

HANOI is a graphic demonstration of the solution to the legendary Towers of Hanoi problem. Requires Microsoft Windows.

FIFTEEN is the classic number puzzle done for Windows. It's a great little time waster when you can't face Excel for one minute longer. Requires Microsoft Windows.

TREK is a classic Star Trek game made bolder still with the addition of EGA graphics. It's a rich, intricate adventure set against the backdrop of uncharted space. Sounds like a good plot for a TV show of some sort... Requires an EGA card.

GRAFCAT is the latest... and vastly expanded... version of our popular graphics catalog program. It prints 16 images to a page on any LaserJet compatible or PostScript printer, and works with a mixture of PCX, IMG, MacPaint and GIF files. The colour pictures get dithered. This is a great tool for users of desktop publishing software.

DISK AT A GLANCE is a great little program for figuring out where all your hard drive space has gone. It lets you walk through your subdirectories and see what's stored where.

STARTER is a Windows application starter that's a lot easier to use than the main Windows screen if you use the same programs all the time. Requires Microsoft Windows.

WHEN is a time management tool which will let you set alarms for yourself, plan your days weeks ahead and generally make sense of a busy schedule.

HOTRES is a rather brilliant little program which will make any normal DOS program into a pop-up utility.

ALIAS is one of the most sophisticated DOS command line editors we've encountered to date. It replaces DOSEDIT with some powerful new functions.

REWRITE is a lifesaver for anyone who has a quad density, 1.2 megabyte drive. If you attempt to write to a regular 360 kilobyte disk in one of these things, it frequently becomes unreadable in a regular dual density drive. This program undoes the damage. C source is included.

SPICE is an extensive cross reference generator for spices and herbs. It helps you choose spices which will best compliment your food.

CREEPS is a one of those apparently simple but maddeningly addictive ASCII arcade games. Requires a few hours to burn as you scoot between the blocks blasting the creeps Requires a CGA, EGA or VGA card.

DIS86 is a diabolically clever machine language disassembler. It allows you to actually trace you way through the jumps and calls of a object file to see what everything does.

MOVE is a really reliable file mover. It copies your files from place to place and then deletes the originals.

LIFE is a really slick implementation of the classic simulation of life done for Windows.

VGAFONT will replace your boring IBM VGA font with a slick, modern looking one. Requires a VGA card.

ADULT TRIVIA is something like trivial pursuit with a one track mind. It's both entertaining and educational... and rude. Please note that this game is quite explicit in places... most places... and may not be suitable for young or sensitive users. If you plan to give this collection to the kids, we recommend that you delete this game.

CONQRDEX will generate a concordance index from any text file. It's great for creating book indexes and tables of contents.

HOG is a glorious graphic pie chart which will visually display how your hard drive is being used. It spots the disk hogs. Requires an EGA card.

DQ is a file browser for database files. It works with DBF files from dBase, FoxBase and all the other dBase compatible programs. This is a genuinely essential program for anyone who works with database managers.

AGE will ask you questions about yourself and your lifestyle and tell you want your physiological age really is. It's rather sobering.

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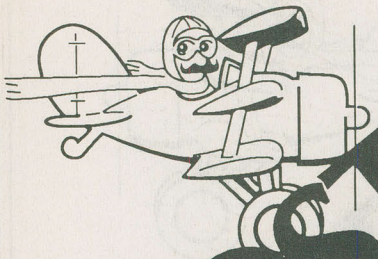
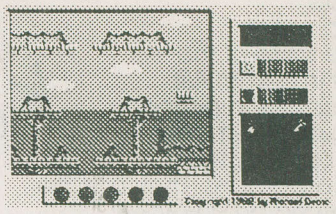
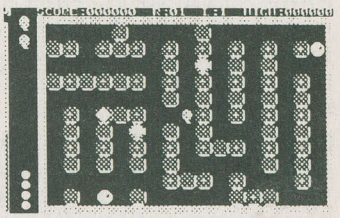
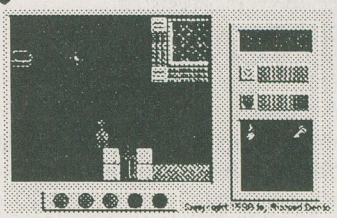


ALMOST FREE GAMES

VOLUMES TWO, THREE AND FOUR







Computer games are what makes suffering through dBase, Lotus and Word Perfect really worth it. We've assembled some of the best public domain PC based games in the following collections. Buy one of these disks and you'll get no useful work done for at least a week.

This collection carries the same promise that all our Almost Free Software does. If you don't feel that it's fair value once you've checked it out, we'll buy it back from you with no gripes or questions.

If you have problems with it, our help desk is as near as your phone... just call (416) 445-5600.

Almost Free Games Volume Two

BRICKS is a classic implementation of "Little Brick Out", a game which dates back to the earliest personal computers. Kill bricks and relive a bit of history.

FLEES is a lightning fast, arcade quality alien slaughter game... get the space fleas a'for they get you. Slaughter and green blood abound. Requires an EGA card.

PANGO is a rather strange little arcade game. You wander around kicking the hell out of bricks and squashing bees. It's fast and peculiar.

PIRATE is a huge graphic adventure game in which you wander through tunnels searching for buried treasure. The pictures are good, the plot is clever and gory, violent death awaits you. Fun for the whole family if they're a bit blood thirsty.

PITFALL pits you against the most dreaded space enemy of all... gravity. Pilot your ship down through the pit without getting mashed on the rocks.

RIBIT2 is the best public domain implementation of frogger we've encountered for a PC. Get your frog across the highway without having it run over.

ROUND42 is a peculiar little effort along the lines of space invaders. However, it's fast and evil, and will take you a long time to get the better of it.

STRIKER puts you in command of an attack 'copter flying into enemy territory. It's all done with pretty slick graphics, from the chopper itself to the missiles which will blow you into the next game room. Just like an arcade but it doesn't need quarters.

SUBCHASE is a graphic war game. You sail along dropping depth charges on unsuspecting subs. They frown on this sort of thing now, but it was very trendy in the early forties.

Almost Free Games Volume Three

CAPTAIN COMIC is the best video game ever written for the PC, commercial or otherwise. Reminiscent of the Dark Castle graphic adventures for the Macintosh, it lets you guide your purple faced hero through a complex graphic world, picking up things, blasting monsters and ultimately finding the... well, we won't tell you what he finds. Requires an EGA or VGA card.

3-DEMON is three dimensional pacman. Wander through corridors picking up food pellets and avoiding ghosts. Requires a CGA, EGA or VGA card.

QIX is an ASCII version of the arcade game. It's fast and runs on any card.

RACECAR is a brilliant ASCII game that lets you drive through a writhing, debris strewn course of death and disaster.

SEAHUNT is a computerized battleship game. It involves strategy, skill and a grasp of military tactics. You also have to like sinking ships.

Almost Free Games Volume Four

SUSAN is a straight text adventure style game. The object of the game is to talk Susan into bed. Not exactly reluctant, Susan is not an easy date, either. This game contains adult situations, and should not be played by ruggies... who won't understand it anyway. If you plan to give this collection to the kids, we recommend that you delete this game.

PODWARS is a fast ASCII graphics game in which you get to cruise around levels of a space ship picking up things and killing other life forms. All that quest and slaughter is a lot of fun. Playable on any machine.

STAR GOOSE is a brilliantly conceived, gloriously executed graphics arcade came. It lets you fly a space ship over very weird alien terrain, blowing things up, flying into the jaws of death... literally... and picking up giant floating eyeballs. If the explanation is already leaving you behind, you really should play Star Goose and find out what it's all about. Requires an EGA or VGA card.

QUAD ALIENS is the strangest thing ever to infest a computer, and the mind which devised it was obviously pretty warped. The plot is all but indescribable... you get to wander around rooms that look like Luke Skywalker's worst nightmare, pushing things out of the way while you try to keep a reactor from going critical and blowing you to kingdom come. Even if you never work your way through it all... which is quite possible considering its complexity... Quad Aliens is worth it just to watch all the action. Requires a VGA card.

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ALMOST FREE COLOUR CLIP ART

VOLUMES SIX AND SEVEN

These disks represent the state of the art in computer graphics, digitized full colour images which look like photographs. They can be viewed on any VGA compatible display card and monitor, and the luminous quality of the images will leave you wondering how civilization existed before the advent of twenty-four bit colour.

Each of our colour clip art collects consists of two quad density disks which hold over a megabyte of image files each. Most of the pictures have at least 640 by 400 pixels, meaning they'll fill the screen of even a super VGA card.

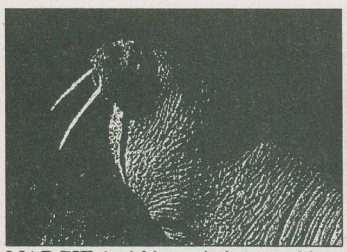
If you own a system with a VGA card, you owe it to yourself to own some of these incredible files. A simple viewing program is included with each disk, and a more powerful image viewing system is available on our GIF User's Toolkit disk, available separately for $24.95.

Desktop publishing users will find these files particularly interesting, as they can be halftoned or dithered into superb black and white clip art. Examples of the dithered files are featured on this page. Our Graphic Workshop package, which created these dithered files, is also part of our GIF User's Toolkit, and will be featured on our Almost Free Software disk next month.

PLEASE NOTE THAT SOME OF THE FILES ON THESE DISKS ARE NUDES, AND MAY NOT BE SUITABLE FOR VIEWING BY YOUNG OR SENSITIVE USERS.

Colour Clip Art Volume 6

HUMMINGBIRD A surrealistic hummingbird near some existential flowers.



MARGIE A girl in a windstorm with unusual makeup.

MBDUFFEK Woman reclining.

ASTRONAUT An astronaut floating above the earth.

SILK One wonders if silkworms really know what they're up to.

PIGS Bacon on the hoof, Pink Floyd grounded.

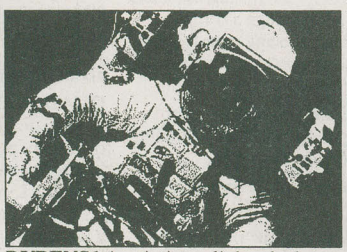
PAULINA Head and shoulders.

ALISON Probably not her real name.

MOLISA A woman of the future, the girl to excite your computer.

VGADNA Part of the double helix.

APPLE A hand painted apple.



RUBENS1 A painting... light, shadow and other artistic stuff.

FANTASIA Mickey Mouse and some special effects.

RUBENS3 More light and shadow.

BEAUTY Conceptual art.

WALRUS A walrus on a rock, singing.

THINKING A woman with something on her mind.

GILDA2 Probably also not her real name.

HENGE Stonehenge at dawn, just before the tourists get there.

Colour Clip Art Volume 7

IRELAND Or a very small part of it.

BARTON A landscape... motel art come to life.

TORNJNS The effects of excessive wear on Levis.

EXCALID A woman and her motorcar.

LEOPARD A big cat.

OCEAN After bathing at Baxters...

HELMET Two of them, actually, along with some aircraft.

BICYCLE Woman on bicycle.

AWAKE Looks like about one in the afternoon.

LENSMIRR A stunning bit of ray tracing.

TIGER1 Another large cat.

BRANDI Almost certainly not her name.

PILLOW A girl and her pillow.

LUNA The moon as seen from somewhere closer than here.

CLOWN A fellow with a large nose and excessive makeup.

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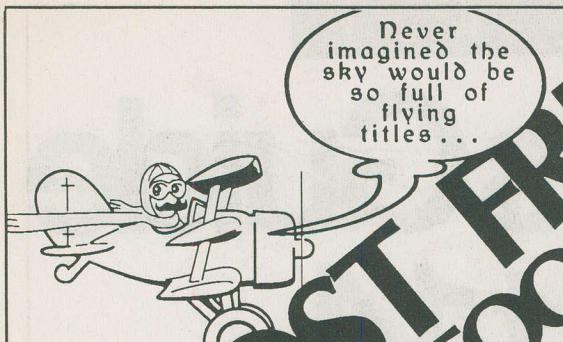

ALMOST FREE WINDOWS TOOLBOX

VOLUME ONE

Microsoft Windows is one of the few truly universal user interfaces. It's equally approachable by new users and experienced professionals, and it makes any application written for it a nicer place to be.

In this collection we've assembled an assortment of public domain Windows applications. Some are just unique little gadgets, others powerful programs to make your Windows environment more productive. All of them, though, represent the power and functionality of Windows.

If you use Windows, there'll be at least one of these things that you won't want to be without.

Every program on this disk has been extensively checked to make sure that it functions as it should and that it contains no viruses or other nasties. Most sources of public domain software do not provide you with this assurance.

This disk carries the same promise that all our Almost Free Software does. If you don't feel that it's fair value once you've checked it out, we'll buy it back from you with no gripes or questions.

If you have problems with it, our help desk is as near as your phone... just call (416) 445-5600.

This collection is only available on quad density disks. Please note that this disk requires Microsoft Windows to run. Windows itself is not included.

FIREWORKS is a screen blanker which will save your monitor by fading to black after a preset time of inactivity. While it's sleeping, it displays random pyrotechnics.

GLOBE shows you the world... rotating, at various magnifications and going in any direction you please. It's cheaper than an airplane ticket and not as likely to get delayed. This is a French version... it's the best globe we've found.

FISHES is a aquarium in a window. Everyone ought to have one of these.

FREEMEM puts up a window which tells you how much free memory you have available.

DIGCLOCK puts up a tiny window which tells you the time. This is not as sophisticated as the analog clock window, but it takes up a whole lot less space.

SNAP copies parts of your screen to the clip board.

HEXCALC is a hexadecimal calculator.

FUSE is just an attractive window to fill an otherwise unused corner of your screen.

COMMAND POST adds features to Windows, making it a lot easier to use and get around in.

CMDTREE runs with command post to make changing directories dead easy.

TETRIS is the classic Soviet falling block puzzle done for Windows.

PUZZLE is a puzzle game with a twist. Assemble the scrambled faces. Comes with an assortment of faces to choose from.

BOUNCE is a really slick bouncing planet window. While perhaps not all that useful, it's a hoot to watch.

CREDIT is a Windows credit card manager. If you live by plastic, this program will keep you from dying by it too.

DESKTOP is another Windows command shell, this one with a configurable user interface. It was a hard choice between this program and Command Post, so we've included them both.

GCP is a graphics tool for Windows. It allows you to look at and manipulate most of the popular paint file formats, including GIF and PCX. Has astounding dithering facilities.

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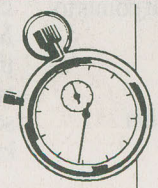

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FEATURE

The Techie's Guide to C, Part 14

This month we're going to have a look at some of the more intricate bits of indirection, pointer notation and other C language nasties.

Steve Rimmer

The nature of C, with its local variables and structurally isolated blocks of code, makes for creating programs quickly and with far fewer bugs than would crop up under a language like BASIC. C also lets you keep all your data together in data structures, a facility which makes dealing with complex blocks of data a lot more practical.

The notation for using complex data structures under C is a bit obtuse, perhaps made more so by the responsibility the compiler places on the shoulders of programmers for differentiating between objects and pointers to objects.

This month we're going to try to make sense of the pointer problem, looking at exactly what a pointer is and what it points to.

It's Rude to Point

If you have a line of C code like this

```
char b[64];
```

you will set up a sixty-four byte buffer... or more properly, an array of *char* variables... somewhere in memory. However, C never lets you deal with complex data types, such as array, directly. As a result, *b* does not contain the array itself. It's a pointer to the array. The size of *b* is two or four, rather than sixty-four.

The size of *b*, and of any pointer, is determined by the number of bytes needed to form a pointer under your compiler's current memory model. This will be two bytes for a sixteen bit pointer under the small and tiny models and four bytes for a thirty-two bit pointer under the large and huge models. Don't worry about this if you don't understand it... it's not all that important at the moment. For the most part, C insulates you from having to know how big a pointer actually is.

This bit of C code will print a string which you have subsequently stored in *b*, above. We'll assume that you've actually done so.

```
puts(b);
```

Now, as you'll recall from previous installments of this series, when you do something like this, C actually copies the argument... *b* in this case... onto the stack so the function it's calling, *puts*, can find it. If we were to pass *b* as an object, this would mean copying sixty-four bytes onto the stack. More than this, though, it would mean that the compiler would have to keep track of the size of every object it uses, and there are several sorts of objects which it cannot know about.

For this reason, the compiler stores pointers to large objects. Simple objects, such as *int*s, *double*s and *char*s are passed directly on the stack. Everybody else gets to use pointers.

Because arrays are always dealt with through the use of pointers, C lets you treat them pretty loosely. Data *structs*, which we've discussed previously, are declared as objects and passed through pointers, so C forces you to distinguish between them when you use struct variables.

Keeping this straight is one the biggest headaches for new C programmers.

Let's see how these pointers work. Here's a struct variable type being declared.

```
typedef struct{
char name[40];
double annual_income;
int number_of_dogs;
}HUMAN;
```

This is all the pertinent information about a person for a program which correlates annual income with the number of dogs the person in question owns. The ultimate usefulness of such a piece of software will be left for discussion some time in the far future.

We can begin by declaring a variable of this type.

```
HUMAN h;
```

At this point, *h* is an object. As such, we might set the name of the person in question like this.

```
strcpy(h.name,"Augustus L. Fizzbatt");
```

The expression *h.name* appears as a string pointer in this case, a pointer to the part of the variable *h* where the string called *name* is to be stored.

Now, here's where things let a bit tricky. Let's say that we have written a function which takes a HUMAN variable as input and returns a mutt factor. A mutt factor is a number which relates the income of the person in question to his or her dog count, the exact nature of which is irrelevant to this discussion. Here's the function.

```
mutt_factor(n)
HUMAN *n;
{
int mutt;

/* calculate the mutt factor */
```

```
return(mutt);
}
```

Now, in this function, *n* is not a struct variable of the type HUMAN, but rather a pointer to it. As such, if we wanted to change the contents of the *name* field in the variable from within this function, we would have to use slightly different notation.

```
strcpy(n->name,"Ivor X. Wombdecker");
```

Likewise, if the calculation of the mutt factor involved multiplying the two numeric values together, it would be done with this "arrow" notation.

```
mutt=(int)(n->annual_income/1000)*
n->number_of_dogs;
```

Type Checking

Another of the things which confuses new C programmers is C's propensity for type checking. In the process of compiling your program, the compiler will make sure that you don't attempt to use a pointer to one sort of object to reference another.

For example, if you create a pointer and a struct like this,

```
char *p;
HUMAN h;
```

the compiler will not allow you to do this without spitting out a few warnings.

```
p=h;
```

In reality, all pointers are the same under the skin, but the foregoing use of *p* is almost guaranteed to cause some problems later on.

There are certainly occasions in which it's desirable to interchange pointers, but in these cases C wants your assurance that you're doing so explicitly, and that you know what you're up to. This process is called *casting*.

This is a legal cast.

```
p=(char *)&h;
```

There are all sorts of perfectly respectable reasons for doing this sort of thing. For example, if you wanted to zero all the fields in the struct variable *h*, you could do it this way.

```
memset((char *)&h,0,sizeof(HUMAN));
```

The *memset* function expects to have a *char* pointer as its first argument.

A struct variable can have any combination of objects as its component fields. This includes other structs. For example, you might define a new struct variable like this...

```
typedef struct{
char breed[32];
int age;
int brain_cell_count;
}DOG;
```

We can now redefine our HUMAN struct to include this new information.

```
typedef struct{
char name[40];
double annual_income;
int number_of_dogs;
DOG the_dog;
}HUMAN;
```

This struct now allows you to store information about one dog. You would access the DOG variable just like any other variable, but the notation for getting at *its* component parts may be a bit obtuse.

In order to change the breed of the dog in the HUMAN variable *h*, you would do this.

```
strcpy(h.the_dog.breed,"Dead poodle");
```

You can nest structures like this for as many levels as you like.

Structs can be placed in arrays, and you can have arrays of structs. This declaration creates an array of sixteen HUMAN variables.

```
HUMAN h[16];
```

Having done this, you would access the eighth entry in this array as follows.

```
strcpy(h[7].the_dog.breed,"Dead poodle");
```

Note that under C, arrays start with the zero'th element. If you want to access the eighth element, you would specify element seven.

The problem with this declaration for the HUMAN variable is that it doesn't allow for more than one dog per owner. It's hard to understand why anyone would want more than one dog... or even one dog at all, come to think of it... but you might want to change the declaration to allow for this possibility anyway. This involves having an array of DOG variables in the declaration for the HUMAN variable.

```
typedef struct{
char name[40];
double annual_income;
int number_of_dogs;
DOG the_dog[4];
}HUMAN;
```

This allows for up to four dogs per owner, which seems like it should take care of even the most masochistic possibilities.

This is how you would change the breeds for all four dogs in a HUMAN variable.

```
strcpy(h.the_dog[0].breed,"Dead poodle");
strcpy(h.the_dog[1].breed,"Brainless setter");
strcpy(h.the_dog[2].breed,"Overfed mastiff");
strcpy(h.the_dog[3].breed,"Plastic spaniel");
```

On Bounds and Arrays

Under BASIC, if you declare an array with twenty-five elements and you attempt to access the twenty-sixth, BASIC will complain and stop the program. C does not do this. If you have an array of HUMAN variables with twenty-five humans in it and you attempt to write to something beyond this, C will go ahead and let you. If there's some useful data after the declared space for the array it will be trashed. If there's some code there, your program will probably detonate.

C does not check array bounds because it rarely knows what they are. For example, let's say that you wanted to store an array of two thousand HUMAN variables. You could do this.

```
HUMAN h[2000];
```

You compiler would probably reply with this.

```
Too much static data allocated.
```

Even if it didn't, this is a very inefficient way to handle a big array. It would be much better to use the *malloc* function to allocate a big buffer, put your HUMAN variables in it and then blow the buffer away when you no longer need it. However, even though this buffer can be made to behave just like an explicitly allocated array, C can't know how big you've made the buffer and, hence, it can't know the bounds of the array.

It's exceedingly important, in dealing with arrays and complex variables, that you keep in mind that under C you are responsible for keeping you data within the bounds you've set up for it.

FEATURE

Designing with Logic, Part 1

Even the latest generation of microprocessors with zillions of transistors on a chip are, at heart, based on simple binary logic. This month we'll start looking at some of the principals behind this essential area of electronics.

Steve Rimmer

Digital logic is often among the most misunderstood areas of electronic applications. If you come from a background of analog circuitry, logic design can be baffling. While logic circuitry is based on the same sorts of devices as other types of circuits are, the input and output of a logic circuit consists of connections of states rather than of signals *per se*. Conventional approaches to design don't really work when they're applied to logic.

It's often possible to design and debug logic circuits without ever powering up an oscilloscope.

For the next few months, we're going to look at the basics of computer logic. Logic design can be applied to simple circuits which just happen to use logical elements as well as to complex hardware projects specifically intended for use with microcomputers.

The Gate

There are relatively few essential logical devices, and, as we'll see in the coming months, many of the seemingly complex logical elements which hardware designers use as integrated devices are really just arrays of simple logical elements inside. Part of the usefulness of logic is its predisposition for creating increasingly more complex and functional "black boxes".

Logic deals with "binary states". To keep the discussion simple, and in familiar electrical terms, we'll allow that a binary state is a voltage level. The level zero is represented by zero volts. The level one is represented by five volts. Different logic families treat these values differently, but we'll be talking about generic logical concepts here.

In academic circles, a logic state of zero is referred to as being "false". A logic state of one is referred to as being "true". This will crop up later on.

A single logic state doesn't tell you very much, inasmuch as it can only be in one of two states. The usefulness of logic is in having multiple elements, each with its own independent state.

The simplest logical element is a NOT gate, or "inverter". This is a box which complements the state of its input. If you apply a state of one to its input, its output will be zero. Its logical symbol is illustrated in figure one.

In fact, this device can be seen as the combination of two still simpler elements. The triangular bit is a buffer and the dot at the output is the thing that complements the output of the buffer. In logical terms there is never any need for a buffer, but in practical electronic applications logical signals frequently need to be buffered.

Although it's a bit simplistic at this state, we can represent the functioning of the NOT gate with a truth table. This rational can be applied to all logical elements, and it will turn up as a design tool when we go to actually connecting the logical elements together. Here's the truth table for a NOT gate, or inverter.

INPUT	OUTPUT
1	0
0	1

The next simplest logical element... or, at least, the next most commonly used one... is the AND gate. This is an element which accepts two inputs and produces one output. It works on the rule that if both of the inputs of the gate are high, its output will also be high. Otherwise, it will be low. In logical terms, we would say that if input one AND input two are true, the result of the process... the gate... will be true.

Figure two illustrates the symbol for an AND gate.

This is the truth table for an AND gate.

INPUT 1	INPUT 2	OUTPUT
0	0	0
1	0	0
0	1	0
1	1	1

We can create another gate from this one very simply by adding a dot to the output. The dot, as you will recall from the discussion of the inverter, NOTs everything that passes through it. We call the resulting gate a NAND gate. Its truth table is the inverse of that of the AND gate.

INPUT 1	INPUT 2	OUTPUT
0	0	1
1	0	1
0	1	1
1	1	0

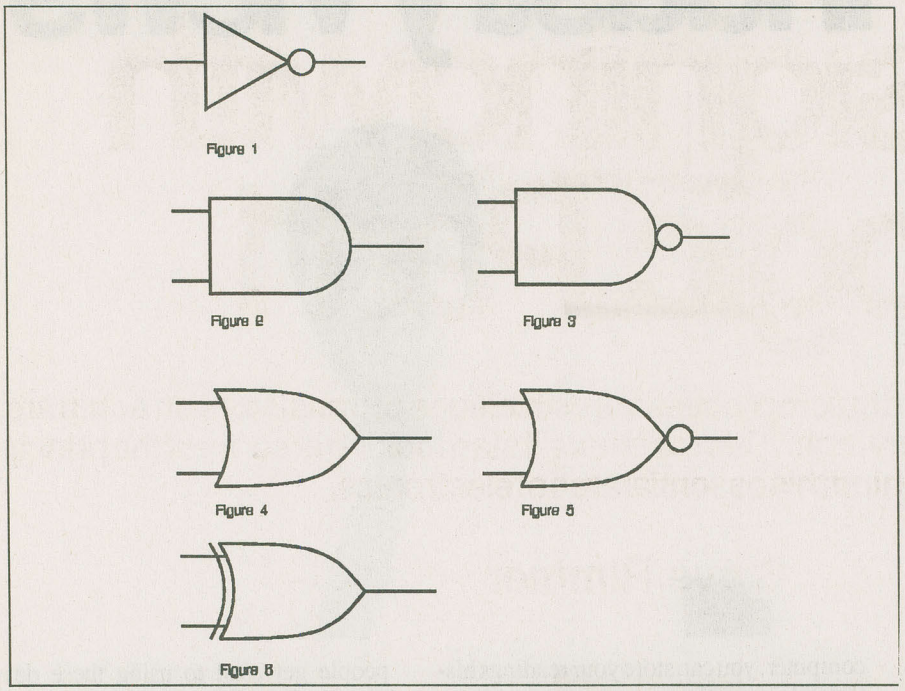


Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

If you've been following the C language series which has been running in this magazine for the past few months, you'll recognize the foregoing truth tables. They operate the same way as does the bitwise arithmetic under C.

The next sort of gate we'll encounter is the OR gate. Its logical symbol is illustrated in figure three. It works under the rule that if either of its two inputs are true, its output will be true. We can write its truth table like this.

```
INPUT 1INPUT 2OUTPUT
000
101
011
111
```

Like the NAND gate, the OR gate will also spawn a negative clone of itself if we tack a dot onto its nose. The NOR gate is shown in figure four. Its truth table, predictably, is the complement of the OR gate truth table.

```
INPUT 1INPUT 2OUTPUT
001
100
010
110
```

NAND gates turn out to be very useful logical elements in designing complex logic circuits. NOR gates are much less frequently encountered.

The final sort of gate to be discussed is the exclusive OR gate, or XOR gate. It has a true output if one but not both of its inputs is true. Its logical symbol is illustrated in figure five. Its truth table goes like this.

```
INPUT 1INPUT 2OUTPUT
000
101
011
110
```

Wiring

Designing with logical elements simply involves putting these gates together to make up a logic array that does what you want. This is a bit like saying that playing classical violin is simply a matter of putting your fingers on the right strings at the right time and moving the bow.

While we will discuss binary arithmetic in much greater detail later in this series, let's have a look at the basis of it now. Dealing with numbers in this way will help you to understand how logical elements are employed to work with numeric values.

Binary numbers are represented as collections of true and false states. For this example, we'll deal with binary numbers from zero through three. These are said to be "two bit" numbers, because they can be represented by two states. We'll call these two state elements line zero and line one. This is how they represent the first four numbers.

```
LINE 0LINE 1VALUE
000
101
012
113
```

The value of line zero is said to be one. The value of line one is two. These are, more properly, one raised to the power of zero in the first case and one raised to the power of one in the second.

Let's create a hypothetical logic element called ADD. This is a fictional gate with two inputs and two outputs. It will add binary values, although as yet we do not know how it works. It has four input lines and four outputs, that is, it will accept two two-bit binary numbers as input and spit out a two bit result. In fact, we need an additional output line for a carry, to be used as a flag should the output exceed the values which are legal for a two bit number.

The truth table for this element would be as follows.

```
INPUT 1INPUT 2OUTPUT
LINE 0LINE 1LINE 0LINE 1LINE
0LINE 1CARRY
0000000
1000100
0100010
1100110
1110001
1101101
1111011
0000000
0010100
0001010
0011110
1011001
0111101
1111011
```

You might want to see if this thing's binary values actually work out right, that is, if for example the result of this binary calculation

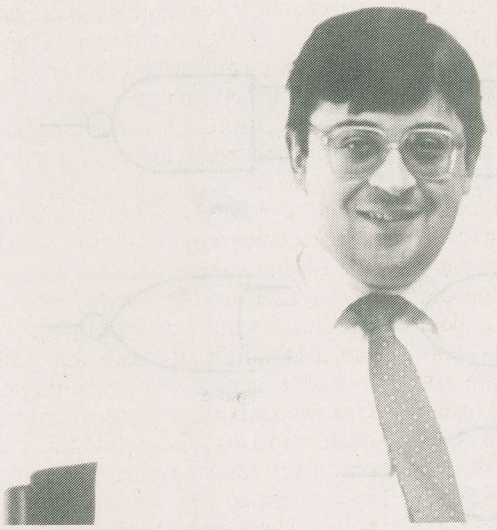
```
LINE 0LINE 1

01
plus10
equals11
```

is actually correct in decimal terms. Let's see how that works. The first input has the decimal value of two. The second input has the decimal value of one. One plus two is three, or at least is was when I checked last. The decimal result of having both lines of a two bit number true is, in fact, three.

Next month we'll design the actual logic array for the ADD element, as well as looking at some additional binary math. ■

Industry Views

Michel Doucet of Techmatron Instruments on the effect of the PC on test and measurement.



Michel "Mike" Doucet of Techmatron Instruments, a supplier of PC-based test equipment, was interviewed on the subject of integrating the computer with the testbench, and the impact the techniques are having on the test and measurement industry. The interview was by Bill Markwick.

***E&TT**: If I start by asking you about the effect of personal computers on test benches, is that too broad a question?*

MD: No, it's a very good question. They've had quite a dramatic effect, because basically every technician has a PC at or near the testbench, whereas a few years ago that wasn't the case. When you had a specific job to do in the past, you took the discrete scope or analyzer or multimeter over to the bench, or you had it permanently hooked up to the bench. Now a lot of these functions can be incorporated into the PC.

***E&TT**: What can computer-based test equipment do for the small operator? Let's say someone who makes small power supplies and wants to test each one for quality control.*

MD: For someone like that who has a PC or XT, there are very low cost data acquisition cards. They give you 12-bit resolution, which translates into 1 part in 4096, you have switch-selectable input ranges, and you can use it in its simplest form as a voltmeter. This lets you acquire data from your power supplies, or if it's audio equipment, you can digitize the audio and then feed the information into the PC. Once the information is in the computer, you can store your readings historically over time, so you can compare production line units if you have enough volume.

You can do statistical analysis on it or analyze waveforms — looking at peaks, or performing a Fast Fourier Transform to get a spectrum analyzer display. All this based on a card that costs no more than $500.

***E&TT**: That's not even as much as a good scope.*

MD: Exactly. We have the advantage that the PC already gives you the ability to display the signal, whereas a scope needs a CRT. The PC also has the advantage that it has a way of storing data — archiving it over a long period of time — and most importantly, you can manipulate it.

The software to do all these wonderful things starts to become the expensive part of the project now, because the hardware is becoming very low cost. The software becomes quite specific to the task you want to do.

***E&TT**: There are now computer-simulated test instruments. For instance, National Instruments, for instance, has a simulated scope front panel on your PC screen — you can mouse over and set the knobs and switches.*

MD: That's right. There are a number of companies that have what I call the "virtual instrument" concept, where they can use a card to make the display look like a scope or voltmeter or frequency counter.

The idea of making it look like a scope with all the separate knobs and switches is an interim measure until people get used to using these devices directly through software. It's a good idea, but it turns out that to put up a graphics display of a scope with the knobs and a mouse to cursor to them requires quite a powerful PC. You need something with the power of a Macintosh, a 286 or a 386.

For people with an XT, that's not really very practical. We sell a product called the Compuscope that turns your PC into a digital scope, and when you're using it with an XT, all you're really capable of doing is displaying the waveform. Additional graphics would make it too slow. It's practical with a 386, but then that takes away the cost advantage of using PC-based instruments.

***E&TT**: It makes you wonder if it's still worth buying test equipment.*

MD: It's still absolutely worth it buying test equipment. The PC- based oscilloscope, which is the one that most often comes to mind, will never replace the traditional scope. The person who's sitting at the bench changing the time or voltage per division will not be happy with PC-based instruments. They must have that instantaneous response as soon as a control is moved. Also, the performance of the analog scope is still superior to what you get in a PC.

What the PC will replace is the digital scope. The digital scope scope uses exactly the same technique as the PC-based; all of the functions can be done on the computer.

***E&TT**: What would someone need to start up, assuming that they have a PC or XT?*

MD: What they need is a card and the software to go with it. If you have a data-acquisition card that measures voltages to 12 bits of resolution and samples at 20,000 or 30,000 samples per second, you can do quite a lot of the functions that you'd associate with a scope, at least for audio work. For RF work, you'd still need to get RF test equipment.

E&TT: What effect are these techniques having on industry?

MD: One area that's really exploding is data acquisition, where people want to monitor temperature, fluid levels, wind speed ot whatever. Traditionally, people bought programmable controllers or data loggers or other expensive and "not-smart" test equipment. Now people can put cards into a PC and do a much better job, because once the data is in the PC it makes it much easier to analyze it than if the information is stuck in a data logger or strip recorder.

E&TT: How are laptops for these applications?

MD: Usually, they only have one or two expansion slots available,a nd you might need four slots if you want quite a complement of equipment.

E&TT: What kind of display do you recommend?

MD: The CGA is completely out. It's not compatible with a lot of the software and the resolution isn't good enough for looking at waveforms. You must have EGA or Hercules, and ideally you'd have VGA. In test and measurement, there's no advantage to going to any of the higher standards such as Super VGA or the 8514.

E&TT: Can you give an example of one of your best-selling products?

MD: Right now, we have one made by the Nohau corporation. It's a PC-based emulator for the Intel 8051 family of microcontrollers, which a lot of Canadian companies use. The in-circuit emulator makes a very nice low-cost development system. There are two boards; one, the emulator, plugs into the PC. The other is called the trace board, and it allows you to emulate the target system on your PC, develop your code in assembler or compiler, and then execute and test it in the emulator before downloading it into your ROMs.

E&TT: Getting back to our hypothetical power supply maker — what card would be best for this application?

MD: The Contec ADC-30. It's a low-cost, general purpose analog input board that sells for $542. It has eight channels of analog input at 30,000 samples per second, 12 bit resolution and two input ranges of plus and minus five volts or zero to ten volts.

In addition, you have four digital output channels, four digital inputs and three channels of counter/timer with input frequencies up to 10MHz. This board can be used for general-purpose process control, data acquisition, measuring frequencies or voltages and all the usual testbench requirements.

The nice thing about this board is that it also comes with utilities in BASIC, so the user has access to all the different functions. There are optional C drivers for people who prefer to write in C, and there are also third-party software packages available, such as the Unkelscope. The Unkelscope is a package that converts this board into a digital oscilloscope. The display gives you the waveform and a movable cursor so you can measure various points. There are no generated knobs and switches; it's all text-based because the graphics are difficult if you're using an XT.

Another possibility is the ADC-50. This has the advantage of having variable gain inputs. This would be particularly useful in an application that used a number of sensors with different output levels; it eliminates having to calibrate each sensor individually.

E&TT: I imagine all the electronics veterans are saying "I wish this stuff had been around when I started".

MD: It basically has made data acquisition using discrete A/D converters obsolete except for people who make appliances or other high-volume devices.

E&TT: Can you get printouts of the generated waveforms?

MD: Yes. If you're writing in BASIC or Pascal, those languages give you the ability to do screen printouts very easily.

E&TT: Does that eliminate the plotter?

MD: No. The plotter is still a very high-resolution device. You can't beat the resolution of a plotter for very accurate readouts. If you have a laser printer and don't mind working in one colour, it would be close to the accuracy of a plotter.

E&TT: This equipment must be revolutionizing testing on assembly lines. You can have unskilled people doing the checking.

MD: That's true. In Toronto, for instance, there's a shortage of technicians and engineers. When that happens, companies have no choice but to turn to automation.

E&TT: What's in the future for PC-based test and measurement?

MD: The OS/2 operating system using the 386 will allow multitasking and windowing, so you'll likely be able to acquire data from one or more windows, send it to something like a spreadsheet in another window, and so on.

E&TT: Lastly, I've noticed that the computer-controlled "smart house" is becoming popular. The data acquisition cards sound ideal for the intelligent house.

MD: Yes and no. The requirements of house control are very simple. For the cost involved, you'd be better off with a programmable thermostat and a commercial burglar alarm. The PC- based system is really more suited to a technical environment.

On the other hand, it would be a lot of fun.

For further information, contact Techmatron Instruments Inc., 1415 Bonhill Road, Unit 17, Mississauga, Ontario L5T 1R2, (416) 564-2588; also with offices in Montreal and Ottawa.

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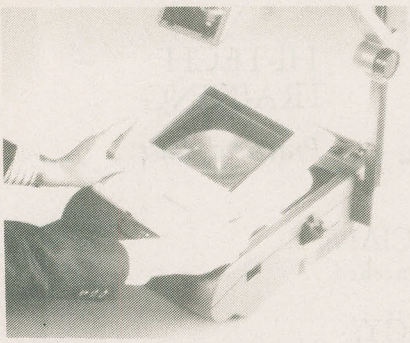

LCD Projector

A line of liquid cyrstal display panels, which project high resolution computer generated data and graphics to a large screen using a conventional overhead projector, has been introduced by 3M Canada. The Model 2080 has true VGA resolution plus downward compatibility with EGA and CGA, while the Model 2024 is designed for EGA and CGA. 3M Canada Inc., PO Box 5757, London, Ontario N6A 4T1, (519) 451-2500.

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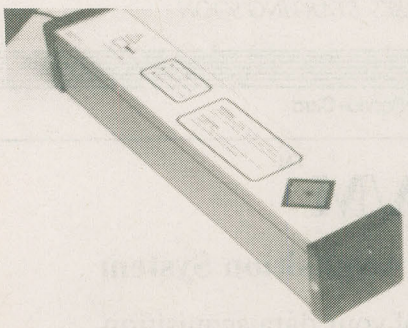


Mini-Review

2mW Laser

If you're looking for a laser for the science lab or other uses, Active Surplus Electronics is offering a 2mW helium-neon unit complete with a power supply for $265. The German-made laser is housed in a sturdy extruded 15-inch case, and the power supply is a 9.5VDC 1A plugpack.

The low power output of 2mW gets this laser a rating of Class IIIa — this means that it emits light only in the visible portion of the spectrum, and "may cause chronic or acute eye injuries to the bare eye". You won't be able to blast holes through anything with this one, but safety precautions are in order.

The tight coherent beam of red light is perfect for optical experiments. Although you can't see the beam unless there's vapour or smoke in the air, it can be seen in a prism, for instance, giving the ideal demonstration of the principles of reflection and refraction. The unit is lightweight, compact, cool in operation, and should be ideal for any low-power laser requirement.

For further information on the laser, electronic components, kits, etc., contact Active Surplus Electronics, 347 Queen St. W., Toronto, Ontario M5V 2A4, (416) 593-0909, Fax 593-0057.

Cache-Memory Fundamentals

Logic Devices Inc., makers of high-speed CMOS chips for computer memory caches, have introduced the L7C series of SRAM chips, allowing clock rates to 50MHz and beyond. The following explanation of computer caches was prepared by Joel Dedrick of LDI. For further information, contact them at 628 East Evelyn Ave., Sunnyvale, CA 94086, (408) 720-8630.

Cache-memory is a design technique used to solve a pervasive problem in high-speed computer architecture: for years, CPU clock rates have increased without any significant change in the speed of the DRAMs used as their main memory. When computers cycled at 200ms and DRAM memory also cycled at 200ns, there was a good match of compute rate and memory bandwidth. As the clock speed of RISC computers and CISC microprocessors has pushed to 33MHz (30ns) and beyond, DRAMs have been left behind.

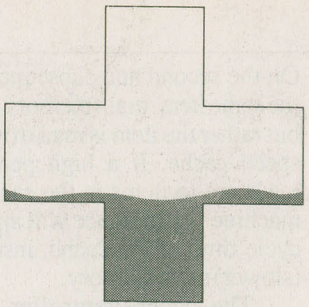
Cache memory solves this problem by taking advantage of a fundamental truth about most software: Almost every program reads and writes the information in memory in tightly clustered groups, rather than at random locations. This phenomenon is called locality. It can be intuitively understood by realizing that most programs include several nested loops. The data and instructions in the innermost loop are generally small, but are executed many times. This, if the access time of this frequently needed date can be improved, overall performance will benefit dramatically.

Cache memory is a small, fast memory inserted between the CPU and its main memory. Cache memory systems consist of two parts: the data memory, and the tag memory. Both are governed by a cache controller. The cache as a whole stores each data item read from main memory by the CPU, in anticipation that it will be needed again. On the second and subsequent reads of the same item, main memory is not used, but rather the item is read from the high-speed cache. If a high percentage of reads are to items in the cache, overall machine performance will approach the cycle time of the cache, instead of the (slower) main memory.

The cache controller is a state machine designed to control the cache resources and direct memory accesses to the cache or main memory as appropriate. Cache controllers are implemented both as VLSI devices and as PAL-based state machines. These approaches trade off performance and complexity for cost.

The data memory stores the frequently-used data items from main memory. The tag memory is a specially constructed SRAM which is used by the cache controller as a directory of the contents of the data memory. When the CPU requests a data item, the cache controller must quickly decide whether the item is present in the cache or not. The tag RAM serves this function by comparing the requested address to the address stored in its internal directory, and indicates whether a match exists. It contains special comparators and a MATCH output for this purpose. The MATCH signal is used by the cache controller as an indication of whether a main memory cycle will be necessary to satisfy the CPU data request.

Cache memory systems are pervasive in PCs operating above 16MHz and in almost all RISC systems. They boost performance far beyond non-cached systems. This will allow manufacturers to design computer systems which will support the enormous performance demands of modern VLSI designs, finite-element mechanical modelling, and other CPU-intensive tasks.



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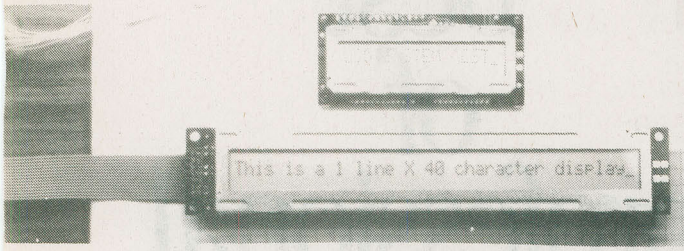

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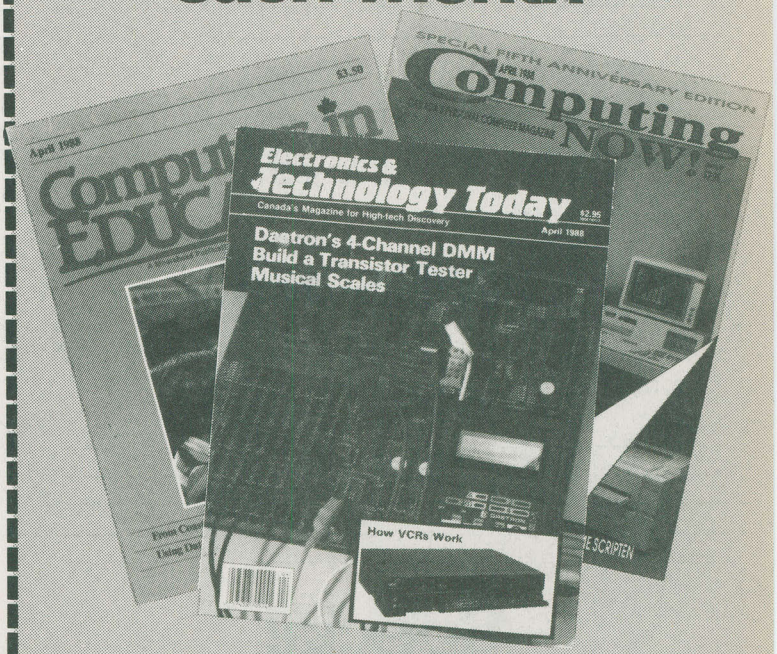

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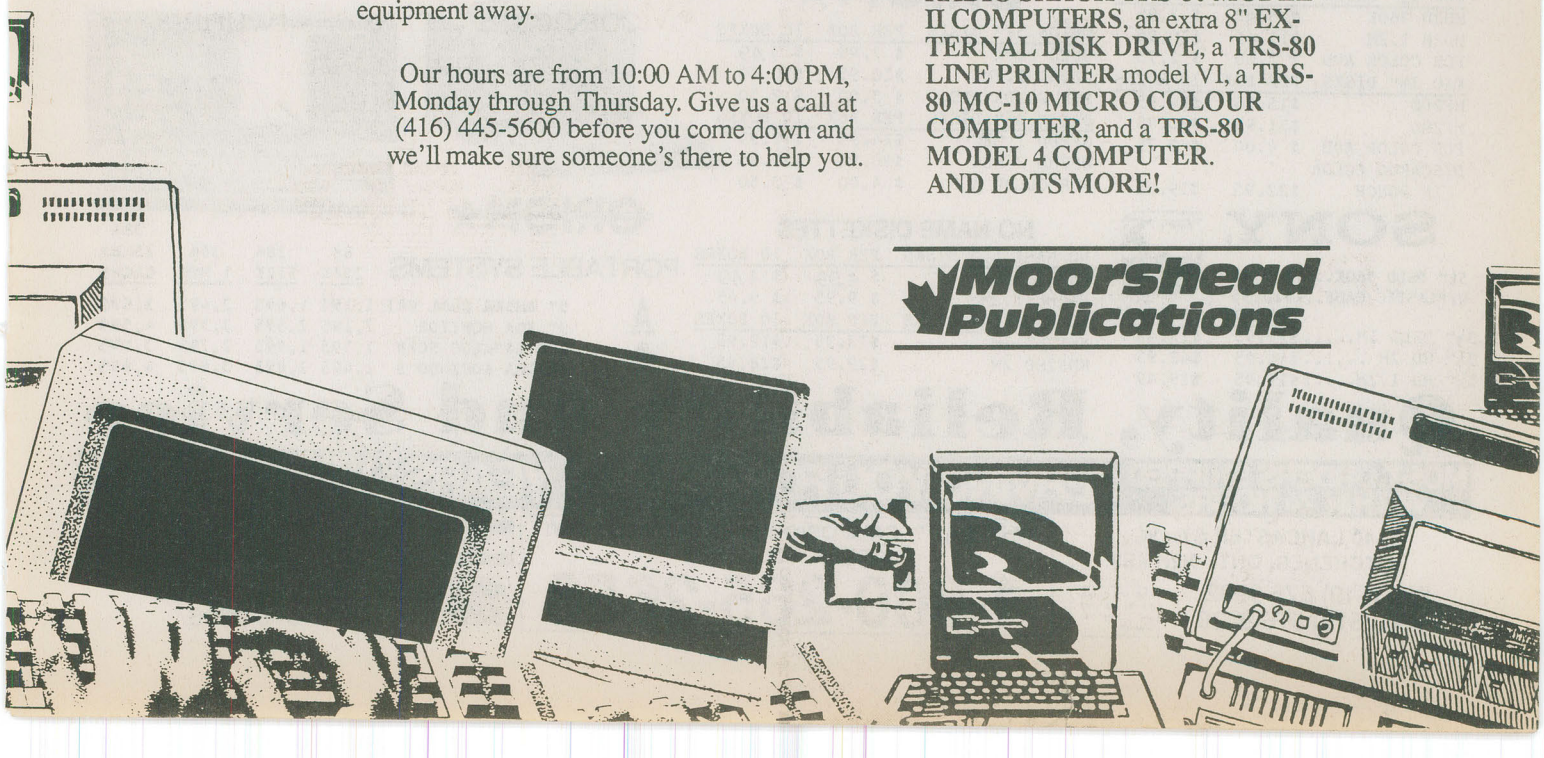

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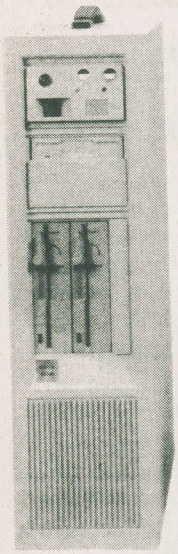

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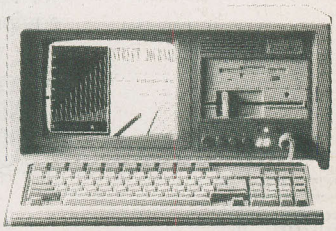

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R.A. Penfold

Projects, fifteen in all, which use a 12V supply are the basis of this book. Included are projects on Windscreen Wiper Control, Courtesy Light Delay, Battery Monitor, Cassette Power Supply, Lights Timer, Vehicle Immobiliser, Gas and Smoke Alarm, and more.

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FEATURE

Understanding SENSEFETs™

Using the current sensing power FET in regulators and switching supplies.

Warren Schultz, Motorola Semiconductors

Introduction

Current sensing power MOSFETs provide a highly effective way of measuring load current in power conditioning circuits. Conceptually simple in nature, these devices split load current into power and sense components, and thereby allow signal level resistors to be used for sampling. Since this technique results in higher efficiency and lower costs than competing alternatives, understanding how to use SENSEFETs is an important design issue.

Getting accustomed to these devices is relatively, but not completely straightforward. SENSEFETs are conceptually simple, but have their own unique set of characteristics and subtle properties. The following discussion examines both, and starts with a description of how SENSEFETs work.

Principle of Operation

SENSEFET operation is based on the matched devices principle that is so commonly used in integrated circuits. Like integrated circuit transistors, the on-resistance of individual source cells in a power MOSFET tends to be well matched. Therefore, if several out of several thousand cells are connected to a separate sense pin, a ratio between sense section on-resistance and power section on-resistance is developed. Then, when the SENSEFET is turned on, current flow splits inversely with respect to the two resistances, and a ratio between sense current and source current is established.

The separate source connection is called a mirror. Typically SENSEFETs are designed such that the ratio between mirror cells and source cells is on the order of 1:1000. Schematically, this looks like two parallel FETs with common gate and drain connections, but separate source leads. An illustration of this configuration appears in Figure 1. The relative size of the two devices determines how current is split between source and mirror terminals. The ratio of source current to mirror current is specified by, n, the "Current Mirror Ratio". This ratio is defined for conditions where both source and mirror terminals are held at the same potential. Since n is on the order of 1000:1, load current is approximately equal to source current, and the current mirror ratio also describes the ratio of load current to sense current.

When a signal level resistor is connected between mirror and source terminals, a known fraction of load current is sampled without the insertion loss that is associated with power sense resistors. For this reason, the technique of measuring load current with SENSEFETs is called "lossless current sensing". As long as the sense resistor is less that 10% of the mirror section's on-resistance $r_{DM(on)}$, the current that is sampled is approximately load current divided by the current mirror ratio or, I_{LOAD}/n. In practice, the amount of sense voltage that is developed with such low values of sense resistance is usually not sufficient to drive current limiting circuits. Therefore, larger values of R_{SENSE} are normally used. These larger values appreciably affect the total resistance in the mirror leg, and, therefore, alter the current mirror ratio. How to model this behavior and calculate sensing parameters is discussed as follows.

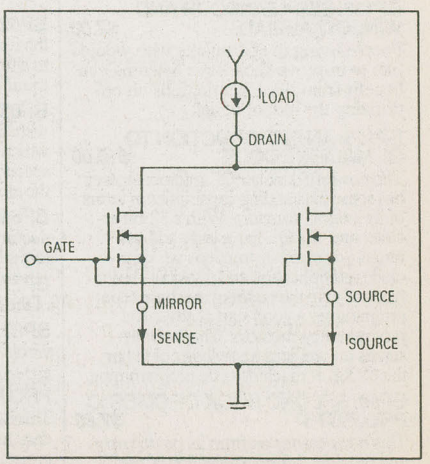

Fig. 1. SENSEFET Equivalent circuit.

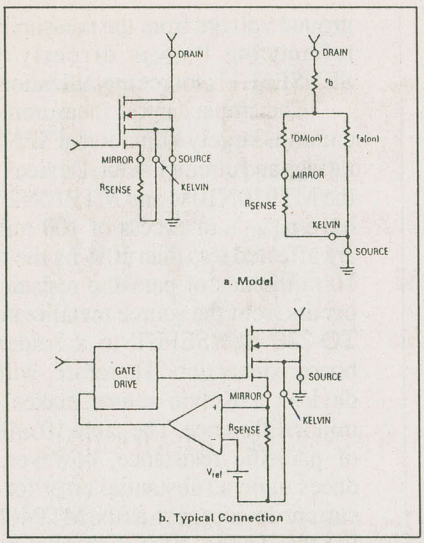

Fig. 2. Model and typical connection.

Calculating Sense Resistance

With the aid of the model that is shown in Figure 2a, calculating sense voltage and sense resistance is very straightforward. In this model, $r_{DS(on)}$ is separated into bulk and active components. Bulk drain resistance is common to the entire device, and is represented by r_b. Active components of $r_{DS(ON)}$ are modeled by $r_{a(on)}$ for the power section, and $r_{DM(on)}$ for the mirror. R_{SENSE} is the external sense resistor.

If R_{SENSE} is an open circuit, the maximum voltage that can appear at the mirror terminal is $V_{DS(on)} \times r_{a(on)}/(r_{a(on)} + r_b)$. In other words, the mirror terminal does not sample the full drain- source on voltage, but sees only the fraction of drain-source voltage that is represented by $r_{a(on)} + r_b$. This ratio is called the mirror compliance ratio, K_{MC}. Values for $r_{a(on)}$ and r_b are determined by measuring the mirror compliance ratio, and multiplying $r_{DS(ON)}$ by this ration to get $r_{a(on)}$. Bulk resistance, r_b,

Table 1. Calculated versus Measured Sense Voltage

R_{SENSE} Ω	Calculated V_{SENSE} mV	Measured V_{SENSE} mV	Δ %
20	51	50	2
47	106	105	1
100	179	185	−3
200	284	290	−2
1 k	480	480	0

is then determined by subtracting $r_{a(on)}$ from $r_{DS(ON)}$. Given these values, $r_{DM(on)}$ is determined by multiplying $r_{a(on)}$ times the current mirror ratio, n.

Given values for the model's internal resistors, sense voltage, sense resistance, and drain current can be calculated from simple resistive divider equations. These equations are summarized as follows:

Sensing Equations

1. $V_{SENSE} = I_D \times r_{a(on)} \times R_{SENSE}/(R_{SENSE} + r_{DM(on)})$
2. $R_{SENSE} = V_{SENSE} \times r_{DM(on)}/[(I_D \times r_{a(on)}) - V_{SENSE}]$
3. $I_D = V_{SENSE}(R_{SENSE} + r_{DM(on)})/(r_{a(on)} \times R_{SENSE})$

The results obtained from using these equations agree very well with measured values. Using the MTP10N10M as an example, calculated and measured values are compared in Table 1. They are based upon 5 amps of drain current, $r_{a(on)} = 116$ milliohms, $r_b = 44$ milliohms, and $r_{DM(on)} = 209$ ohms.

Since all of the actual values were measured on an oscilloscope, the discrepancies which are shown here are all within measurement accuracy. Given static conditions, the model in Figure 2 does a good job.

In a typical application such as the one shown in Figure 2b, a current trip is produced when V_{SENSE} is equal to the comparator's reference voltage, V_{ref}. Therefore, substituting V_{ref} for V_{SENSE} in these equations yields combinations of I_D and R_{SENSE} for which a current limit signal is produced.

For reasons which will soon be discussed, it is generally advisable to choose

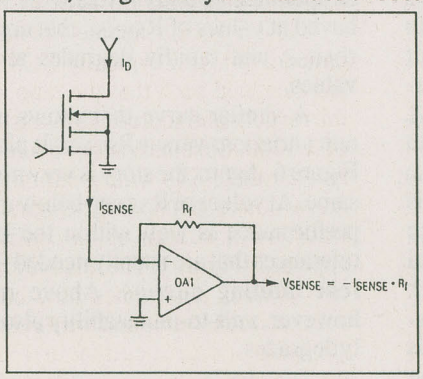

Fig. 3. Virtual ground sensing.

a value of R_{SENSE} that does not exceed $r_{DM(on)}$. As the values in Table 1 indicate, this constraint produces sense voltages on the order of 250 mV at the MTP10N10M's normal operating current. Although this is sufficient for most applications, lower operating current and device types with lower mirror compliance ratios can lead to problems with generating usable values of sense voltage. Where higher values of sense voltage are required, the technique shown in Figure 3 can be used. In this circuit, the SENSEFET's mirror is held at the same potential as its source, and op amp OA1 generates a negative output voltage that equals sense current times the feedback resistor R_f. Sensing equations for this type of virtual ground circuit are listed as follows:

Virtual Ground Sensing Equations

4. $V_{SENSE} = -I_D \times n \times R_f$
5. $R_f = V_{SENSE}/I_D \times n$
6. $I_D = -(V_{SENSE}/R_F)n$

These equations assume that the op amp's input bias current and input offset voltage are both zero. Using some of today's newer op amps, this assumption is a good one. With an MC34081 for example, room temperature values for input bias current and input offset voltage are less than one nanoamp and less than one millivolt, respectively.

Although virtual ground sensing does a nice job of boosting signal level, it requires a negative power supply and produces a negative output signal, both of which can be undesirable. One method of overcoming these difficulties is shown in Figure 4. A dual op amp is used to convert sense current to a negative output voltage, and then invert the negative voltage to produce a positive output. The negative power supply voltage is supplied by a simple and inexpensive 555 charge pump. Running at 60 kHz, this circuit converts the gate drive supply to a local negative rail that is capable of sinking roughly 50 milliamps. For this circuit, sensing equations 4, 5 and 6 apply with the negative signals removed from equations 4 and 5.

Accuracy

The inherent accuracy that is associated with splitting current between matched cells in a power MOSFET is relatively good. Assuming that both source and mirror terminals are held at the same potential, accuracy is solely dependent upon the current mirror ratio, n. This parameter typically runs within +/-1% of nominal at 25°C, is spec'd at +/-3%, and remains within a +/-3% window over temperature.

When SENSEFETs are used in virtual ground sensing circuits, accuracy is a relatively straightforward issue. current mirror tolerance adds with sense resistor tolerance and op amp offsets to produce a sense voltage that is easily maintained within +/-5% over temperature.

Life gets much more interesting when a conventional mirror to ground sense resistor is used. Instead of deriving measurement accuracy from matched on-resistances within a monolithic device, tolerance depends both on internal ratios and the ratio of internal on-resistance to

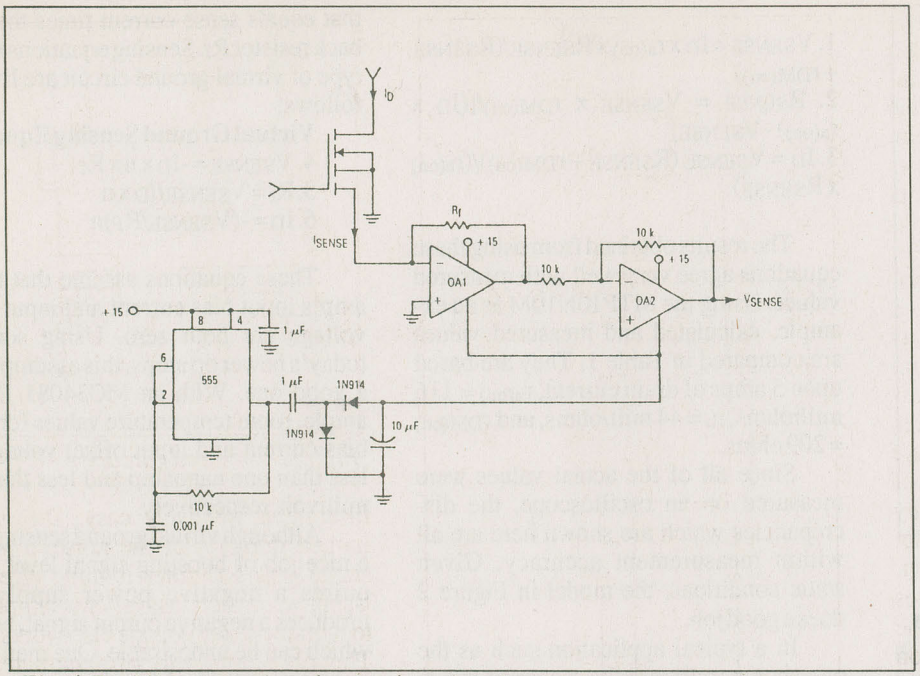

Fig. 4. Positive output virtual ground sensing circuit.

and external R_{SENSE}. Therefore, in this configuration, unit-to-unit variations and temperature stability are first order design considerations.

Referring again to Figure 2, the sensing model provides a schematic illustration of the issues involved. To start, let's assume that R_{SENSE} is equal to zero. In this condition, whatever variations occur in $r_{a(on)}$ are very nearly matched on a percentage basis by variations in $r_{DM(on)}$. Therefore, even for very large changes in $r_{a(on)}$ the ratio between $r_{a(on)}$ and $r_{DM(on)}$ remains nearly constant. Since this ratio is undisturbed, the ratio of sense current to drain current is also undisturbed, and measurement accuracy is relatively good. At the other end of the spectrum, let's assume that R_{SENSE} is an open circuit. In this case mirror voltage is not dependent upon ratios. The mirror terminal samples the voltage drop across $r_{a(on)}$, with $V_{SENSE} = I_D \times r_{a(on)}$. Measurement accuracy is, therefore, directly dependent upon the value of $r_{a(on)}$. Since $r_{a(on)}$ can vary 30% from unit to unit and 100% over temperature, an accurate measurement is not obtained in this configuration. In between these two extremes, choosing R_{SENSE} boils down to a tradeoff between signal level and accuracy. As a rule of thumb, useful performance is obtained with values of R_{SENSE} up to $r_{DM(on)}$. Above $r_{DM(on)}$, however, measurement accuracy is more dependent upon the absolute value of $r_{a(on)}$ than it is on the ratio, and performance degrades rapidly as R_{SENSE} is increased further. An illustration is provided in Figure 5 where temperature stability is plotted versus normalized R_{SENSE}. In this figure, R_{SENSE} is normalized with respect to $r_{DM(on)}$ such that a value of 1 corresponds to $R_{SENSE} = r_{DM(on)}$. Note that temperature stability is relatively well behaved at values of R_{SENSE} that are below $r_{DM(on)}$ and rapidly degrades at higher values.

A similar curve that shows unit-to-unit variations versus R_{SENSE} is plotted in Figure 6. Again, the story is very much the same. At values of R_{SENSE} below $r_{DM(on)}$, performance is well within the kind of tolerances that are usually needed for current limiting circuits. Above $r_{DM(on)}$, however, unit-to-unit stability also rapidly degrades.

Kelvin Source Connection

In order to get the full accuracy that SENSEFETs are capable of, a Kelvin connection to the source is required. Otherwise voltage drops that are caused by load current flowing in the ground connection will add to sense voltage and introduce a source of error. The effect of ground impedance is illustrated in Figure 7 where R_{GROUND} has been added to the model in Figure 2. Load current flowing through R_{GROUND} produces a voltage drop that appears in series with $r_{a(on)}$. In Figure 7a, this voltage adds directly to the open circuit mirror voltage, and affects the measurement proportionately. In Figure 7b, the Kelvin connection removes parasitic ground voltage from the measurement by referencing R_{SENSE} directly to the SENSEFET's source metallization.

The impact upon measurement accuracy is largely a function of SENSEFET ratings and circuit layout. Devices such as the MTP10N10M and MTP10N25M that have $r_{a(on)}$'s in excess of 100 milliohms are affected less than 10% by the roughly 10 milliohms of parasitic resistance that occurs from the source metallization of a TO-220 SENSEFET to a soldered PC board connection. Therefore, with these devices a Kelvin return makes only a minor difference. The same 10 milliohms of parasitic resistance, however, introduces quite a substantial error for higher current devices such as the MTP40N06M. For this device, 10 milliohms of parasitic resistance is an appreciable fraction of its 17 milliohm $r_{a(on)}$, and use of a Kelvin return eliminates what would otherwise be a large error.

Although SENSEFET Kelvin returns are intended primarily to improve measurement accuracy, they also have an important application at higher frequencies. As illustrated in Figure 8, gate drive

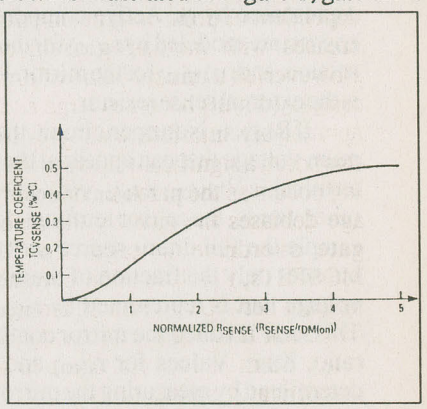

Fig. 5. Temperature stability.

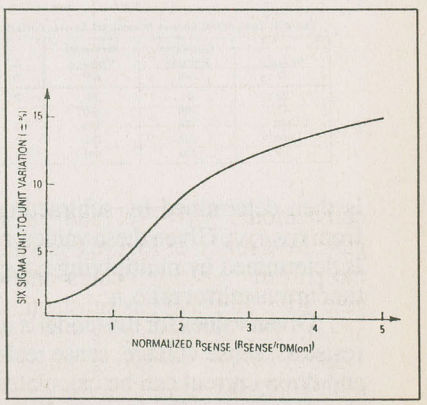

Fig. 6. Unit-to-unit variation.

ground can be referenced to the Kelvin pin instead of a PC board ground plane. This connection bypasses parasitic source inductance, L_S, that is associated with the source wire bond and the source pin. Therefore, the Kelvin connection allows faster switching speeds at higher currents where source inductance becomes a significant limitation.

To illustrate, let's assume that a conventional TO-220 MOSFET is connected such that the only source inductance in its gate drive loop is 8 nanohenries of wire bond and lead inductance. During switching transitions, the voltage drop across this inductance ($V = L_S\, dI_S/dt$) opposes gate drive voltage. As long as the magnitude of this voltage is less than the amount by which the gate is overdriven, no first order affect upon switching times is seen. However, when this voltage becomes high enough to significantly oppose the gate drive, there is a limiting affect upon switching speed.

Since the speed at which a MOSFET's gate can be driven is essentially independent of drain current, switching speed tends to be relatively independent of drain current, and dI_S/dt increases with increasing drain current. However, at a critical value of drain current, $L_S(dI_S/dt)$ becomes large enough to appreciably interfere with gate bias. At this point, a significant slowing of switching occurs as the parasitic opposing voltage debiases the gate by the amount of gate overdrive voltage. To TO-220 MOSFETs, this limitation becomes significant between 10 and 20 amps, where transition times that can easily be held below 10 ns at 10 amps climb to several tens of ns at 20 amps and above.

If a SENSEFET is substituted for a conventional MOSFET and the Kelvin gate drive return of Figure 8 is used, then the parasitic voltage occurs outside the gate drive loop and has substantially less affect. The difference is illustrated in Table 1 where switching times for an MTP10N25M with Kelvin gate drive return and Source gate drive return are compared. In both cases, the test device is switching an inductive load, is driven by a high speed MC33152 driver and is measured with a Pearson model 4028 high speed current transformer.

High Speed Performance		
Drain Current Amps	Kelvin Return Fall Time (ns)	Source Return Fall Time (ns)
5	6	6
10	6	7
15	6	9
20	7	27
25	9	28
30	10	44

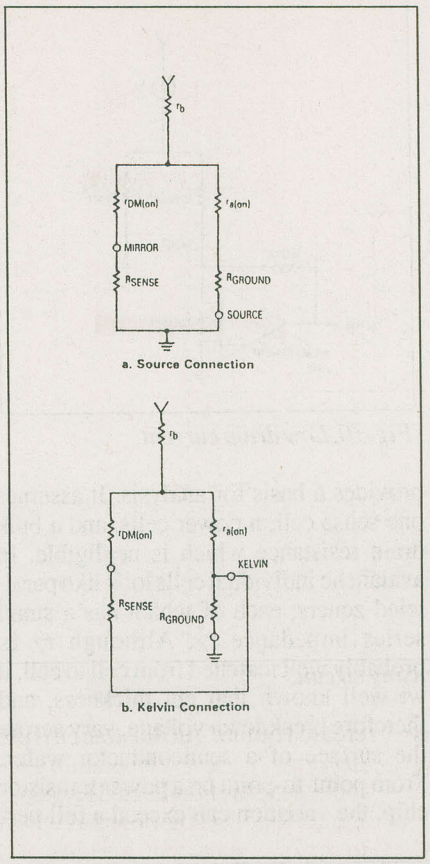

Fig. 7. Ground impedance.

It is readily observed from this data that SENSEFET packaging contributes a significant performance advantage at higher currents, but has no appreciable affect at currents below 10 amps.

Noise Suppression

Particularly at high speeds, noise spikes at both turn-on and turn-off are a first order design consideration in SENSEFET circuits. These spikes are short, roughly the same duration as the switching transitions that produce them, and can be several times the value of the sense voltage that is being measured. They arise from current flow in parasitic capacitances and also from higher sensing gain as the SENSEFET switches through its active region.

Generally speaking, noise at turn-off is not usually much of a problem, since a spike that is large enough to cause current limiting has no affect during turn-off. Turn-on, however, is another matter. Spikes that are routinely seen at turn-on can easily produce false trips that interfere with proper circuit operation. Fortunately, filtering is relatively easy. Due to the limited duration of the noise, a simple single pole RC filter is quite effective. Using an op amp instead of a comparator to monitor sense voltage also works well. The op amp's roll off characteristic provides a single pole filter that causes short spikes to be ignored. Both of these techniques, of course, slow the speed of the current limit loop and may be undesirable in some applications. In these instances digital blanking can be used to disable the current limit comparator for a fixed amount of time during the turn-on switching interval.

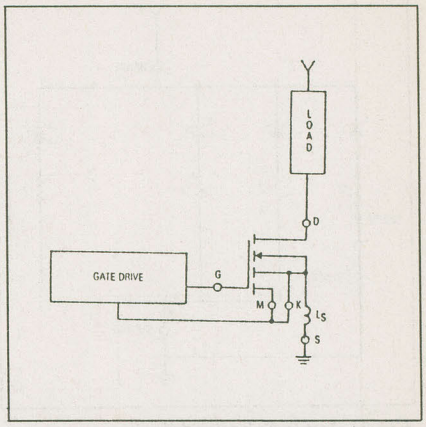

Fig. 8. High speed gate drive.

Whatever circuit technique is used to limit noise, layout is critical when SENSEFETs are used at or near their fastest switching speeds. Printed circuit board construction is a must, and careful attention is required to keep ground currents away from the current sensing loop. Small ground planes, separate grounds for power and sense loops, and single point grounding for power components all tend to make life easier. It is also important to remember that radiated noise can be as big a problem as conducted noise. For this reason it is important to minimize the size of the power ground, which is a radiating surface, and to place sense voltage filters as close as possible to the current limit circuits that they feed.

Sense Voltage Under Abnormal Conditions

For normal steady state operation, sense voltage is determined by resistor ratios which are easily calculated. However, questions often arise concerning sense voltage under abnormal conditions. Operations in avalanche, operation at very low currents, reverse current flow, and reverse recovery of the drain-source diode are considered here.

Understanding Sensefets

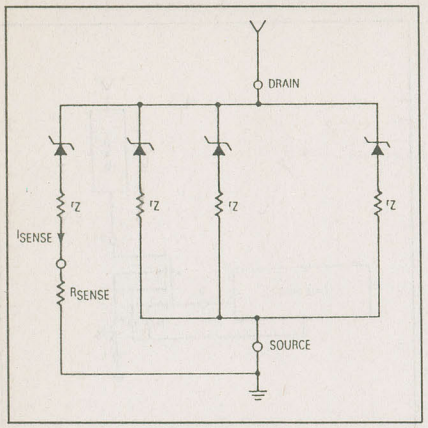

Fig. 9. Avalanche model.

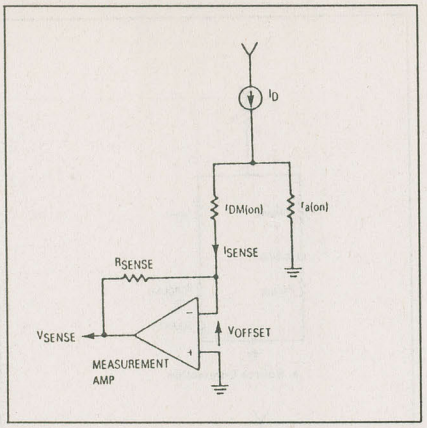

Fig. 10. Low drain current.

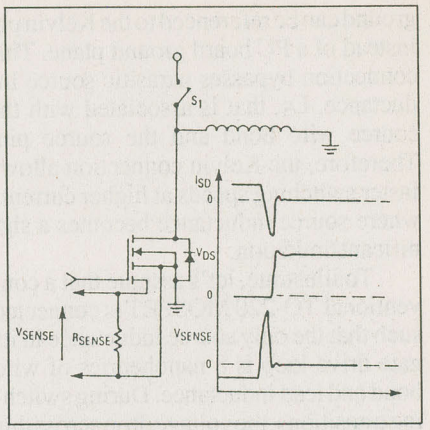

Fig. 11. Reverse recovery.

Avalanche

The latest generation of power MOSFETs is capable of withstanding considerable stress in avalanche. Drain-source diodes have been replaced with drain-source zener transient suppressors. Therefore, inductive flyback voltages can be clamped directly by the MOSFET. SENSEFETs can also be used in this way, which leads to questions regarding sense voltage during avalanche.

The simplified model in Figure 9 provides a basis for analysis. It assumes one sense cell, n power cells, and a bulk drain resistance which is negligible. In avalanche individual cells look like paralleled zeners, each of which has a small series impedance rz. Although rz is probably well matched from cell to cell, it wi well known that epi thickness, and therefore breakdown voltage, vary across the surface of a semiconductor wafer. From point-to-point on a power transistor chip, the variation can exceed a full percent. Therefore, the zener voltages in Figure 9 can be mismatched by a volt or more in situations where the average voltage across rz is measured in tens or hundreds of millivolts. Under these conditions, sense voltage is essentially indeterminate since ISENSE will depend more upon the sense cell's relative breakdown voltage than on the current that is being measured. The net result is that energy rated SENSEFETs will survive avalanche as well as energy rated MOSFETs, but

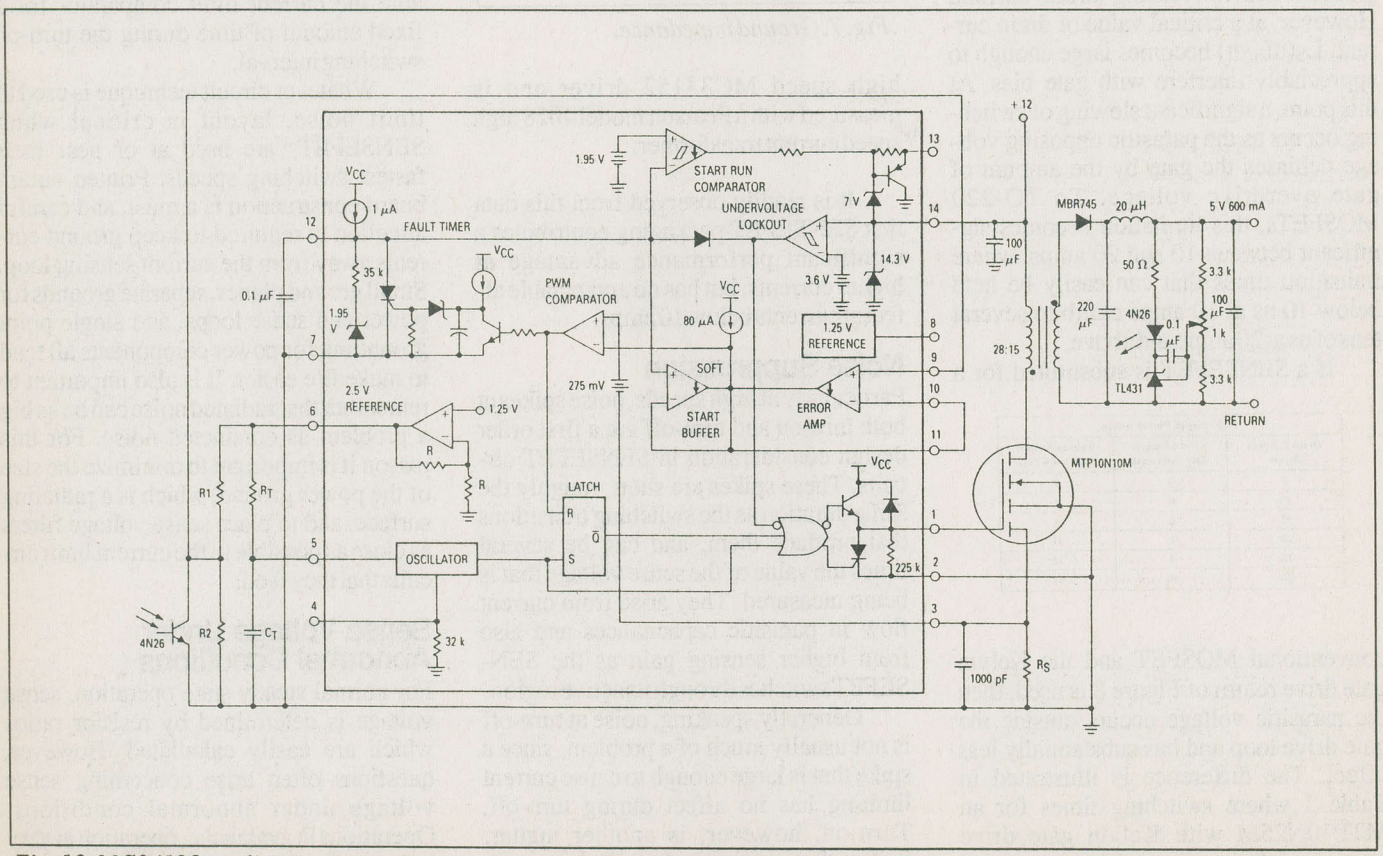

Fig. 13. MC34129 application example.

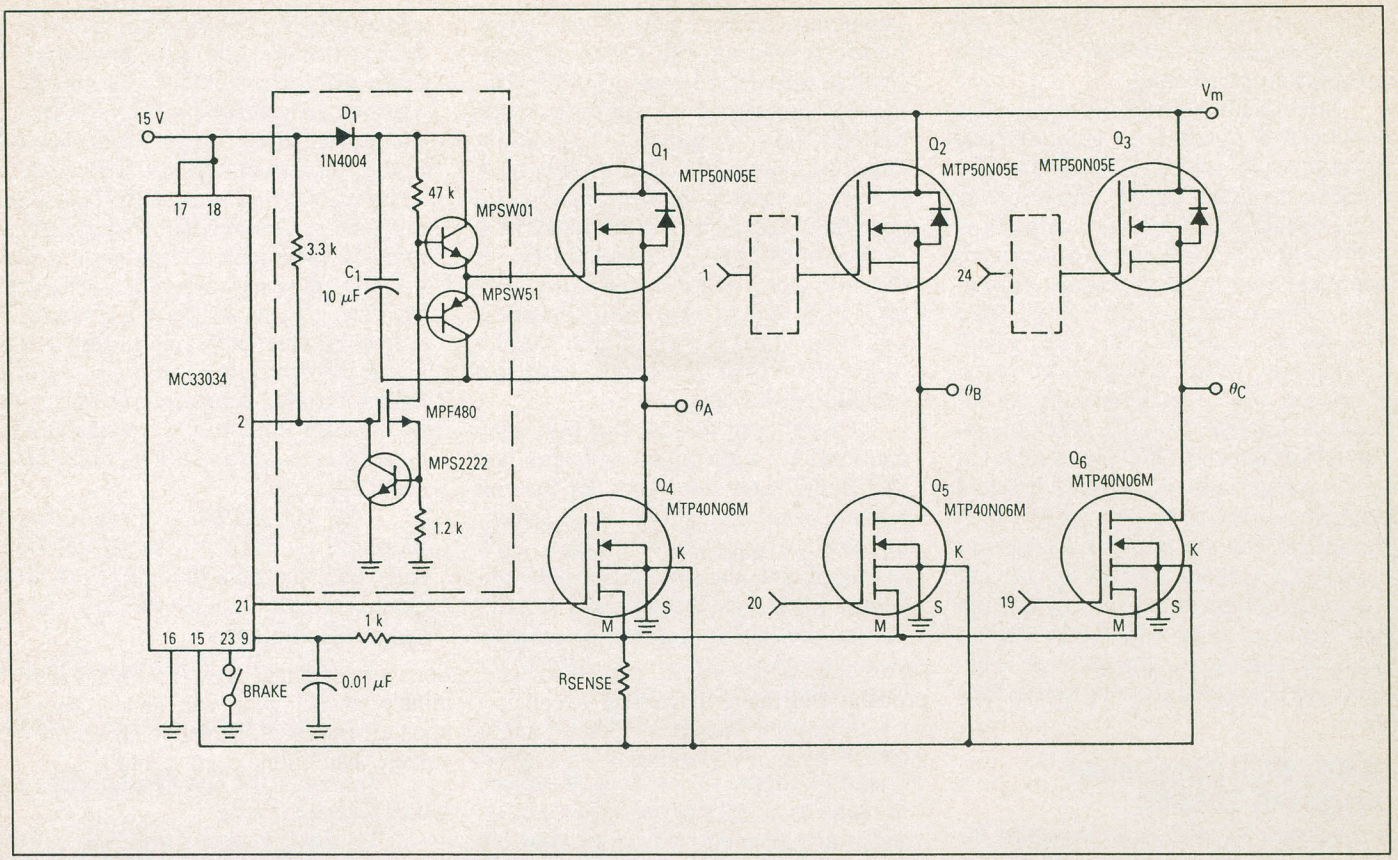

Fig. 14. MC33034 application example.

lose their ability to provide a meaningful current sensing measurement in this condition.

Very Low Drain Current

At normal operating current, offset voltage in measuring circuitry is usually negligible. However, at drain currents below 1% of rated output current, offset voltages have a first order affect on the current sensing measurement. A brief look at the simplified model in Figure 10 explains why. Suppose, for example, that the SENSEFET is an MTP10N25M with an $r_{a(on)}$ of 170 milliohms and an $r_{DM(on)}$ of 145 ohms. With one amp flowing through $r_{a(on)}$ and zero offset in the measurement amp, 170 millivolts is impressed across $r_{DM(on)}$ to develop I_{SENSE}. If the offset voltage of the measurement amp is 1 millivolt, the voltage across $r_{DM(on)}$ is changed by 1 millivolt. Sense current is changed by 1 part in 170, which is less than 1%. Now assume that I_D is 10 milliamps. In this case, only 1.7 millivolts is developed across $r_{a(on)}$. Therefore, a 1 millivolt offset changes the measurement by 1 part in 1.7, and seriously affects the results. In general, at very low currents measurement amplifier input offset characteristics significantly influence measured current mirror ratios, and can cause relatively large deviations from values observed at practical operating currents.

Reverse Recovery

When SENSEFETs are used in bridges, current flow in the drain-source diode can be an important part of circuit operation. If this diode is commutated, in other words switched off rapidly by an opposite half bridge, a significant amount of sense voltage is produced. For example, suppose that inductive load current is freewheeling through a SENSEFET's drain-source diode as shown in Figure 11 and, then S1 closes rapidly. As the accompanying waveforms suggest, a very substantial V_{SENSE} spike is produced as the drain-source diode is cleared. Its magnitude is dependent upon the speed at which S1 closes, the amount of current that is commutated, and the value of R_{SENSE}. Its duration is a function of the drain-source diode's reverse recovery time.

This spike is a significant design issue because it is both large and occurs as a positive signal with respect to ground. To illustrate the magnitude of the problem, consider an MTP10N25M in which 2 amps is commutated in 100 ns. With R_{SENSE} = 100 ohms, the reverse recovery spike has a magnitude of 400 millivolts. Since the forward sense voltage at 2 amps is only 140 millivolts, the possibility of falsely tripping a current limit circuit at very modest currents exists.

Fortunately the duration of the spike is very short. It is limited to the time during which current is being commutated in the drain-source diode. Therefore, a single pole RC filter will easily reduce peak voltage to acceptable levels. Alternately, current limit circuitry can be digitally blanked during the time that revers recovery transitions take place.

Reverse Current

When current flows through a SENSEFET's drain- source diode, anode current is split between source and mirror terminals in a fashion similar to forward mode operation. However, the equivalent circuit for reverse operation is significantly different, as are operating results. As shown in Figure 12, current sensing is dependent upon mirror-to-bulk and source-to-bulk diodes as well as the ratio of cell resistance. As long as R_{SENSE} is equal to zero of effectively held to zero with an op amp, the sense ratio is based upon the ratio of r_{mb} to r_{sb} and matched diode drops. Since the ratio of r_{mb} to r_{sb} is the same as the

ratio of $r_{DM(on)}$ to $r_{a(on)}$, forward and reverse sense ratios match and are equal to n, the current mirror ratio.

When a non-zero R_{SENSE} is added, a significant departure from forward mode operation is observed. Additional resistance in the sense leg does not give the same linear predictable results, because cell resistances in the reverse mode are modulated by minority carrier current flow. These resistances have a first order dependence upon current density and decrease in value at higher currents. Therefore, while matching from cell-to-cell with $R_{SENSE} = 0$ is quite good, any attempt to establish a ratio between the internal resistances and a fixed external R_{SENSE} is met with first order nonlinearities. The net result is a measurement that is accurate within a few percent if a virtual ground op amp is used, and is a poor representation of reverse current flow when practical values of sense resistance are connected from mirror to Kelvin.

SENSEFET Compatible Integrated Circuits

Since power MOSFETs are driven by integrated circuits in many applications, compatibility with integrated circuits is an important issue. As a general rule, current limit comparators with 100 to 125 millivolt sensitivity are required for PWM integrated circuits to be compatible with SENSEFETs. A number of recently developed integrated circuits either meet this requirement or were developed specifically to work with SENSEFETs, such as the MC33152 SENSEFET Driver for microprocessor interfacing, the MC33034 Motor Controller for brushless DC motors, and the MC34129 Current Mode Controller for single transistor switching power supplies.

All of these devices function quite comfortably with output voltages that SENSEFETs provide. They are also all capable of driving SENSEFETs at very high switching speeds. Therefore, good PC board layout techniques are very important when using these circuits. In addition, the use of series gate resistors to slow switching speed can be very helpful for breadboarding and debugging.

Two examples which illustrate how SENSEFETs are used appear in Figures 13 and 14. Figure 13 describes an isolated 12 volts to 5 volt current-mode supply, and is a convenient vehicle for showing how the MC34129 and MTP10N10M work together.

Starting with the oscillator, R_T and C_T are selected for operating frequency and dead time. A combination of 13K for R_T and 1500 pF for C_T produces 28 kHZ operation with slightly less than 50% maximum duty cycle. Ramp voltage is generated by R_S and fed into the PWM comparator's non-inverting input at Pin 3. The ramp's magnitude is determined by using equation 1 and adding - 120 uA of nominal input bias current that flows out from Pin 3. The ramp voltage is, therefore:

$$V_{RAMP} = 57\,mV/Amp \times I_D + 24\,mV$$

Knowing the relationship between V_{SENSE} and primary current, maximum short circuit current is set with voltage divider R1/R2. The output voltage from this divider is coupled through a unity gain Error Amp to set the PWM comparator's upper trip point. To calculate the trip point, 275 mV of offset is added to the SENSEFET's output voltage. With the values shown, R1 and R2 set the upper trip point at 470 mV, and peak current is limited to approximately 2.8 amps.

Turning to the brushless motor drive in Figure 14, an illustration of how the MC33034 brushless motor controller and MTP40N06M SENSEFETs interface with each other is provided. In this figure, six power MOSFETs are connected in a 3-phase bridge configuration to drive a brushless motor. The upper devices are 28 milliohm N-Channel FETs that are driven by a bootstrap technique that is described in detail in AR194. To form the lower half bridge, three MTP40N06M SENSEFETs are directly driven by the MC33034. Since only one of these devices is on at a given time, all three mirror terminals are connected to one sense resistor, R_{SENSE}. With this arrangement, a current-trip threshold is reached when excess current appears in any of the three phases. A single pole RC filter is inserted between R_{SENSE} and the MC33034's current limit comparator to eliminate the noise spikes that inevitably occur at R_{SENSE}.

The MC33034's current limit threshold is 100 mV. Therefore, from equation 2, the value of R_{SENSE} that is required for a desired current limit can be calculated as follows:

$$R_{SENSE} = 0.1\ V \times r_{DM(on)}/[I_{limit} \times r_{a(on)} - 0.1\ V]$$

Plugging in $r_{a(on)}$ and $r_{DM(on)}$ for the MTP40N06M:

$$R_{SENSE} = 0.1\ V \times 16\ ohms/[I_{limit} \times 0.017\ ohms) - 0.1\ V]$$

To obtain a current limit value of 40 amps, for example, these values lead to choosing a value of 2.7 ohms for R_{SENSE}. Since this resistor can be a standard 1/4 watt resistor, it is by far preferable to the alternative of using a 2.5 milliohm 4 watt resistor in series with the ground return.

Conclusion

SENSEFETs are conceptually simple devices that provide an alternative to power sense resistors and magnetics for sensing load current. When using these devices, calculating sense resistance and sense voltage for steady state conditions is relatively straightforward. Other aspects of designing with SENSEFETs require greater familiarity with both characteristics and techniques for dealing with relatively low sense voltages. One subtle characteristic provides an unintended benefit. The Kelvin source connection can be used to attain faster switching speeds than similar devices in conventional 3 leaded packages. Whether they are used for speed or for lossless current sensing, SENSEFETs are well worth becoming familiar with; since circuits based upon SENSEFET designs tend to operate more efficiently with fewer and smaller components. ■

(Courtesy of Motorola Semiconductors, Phoenix, Arizona.)

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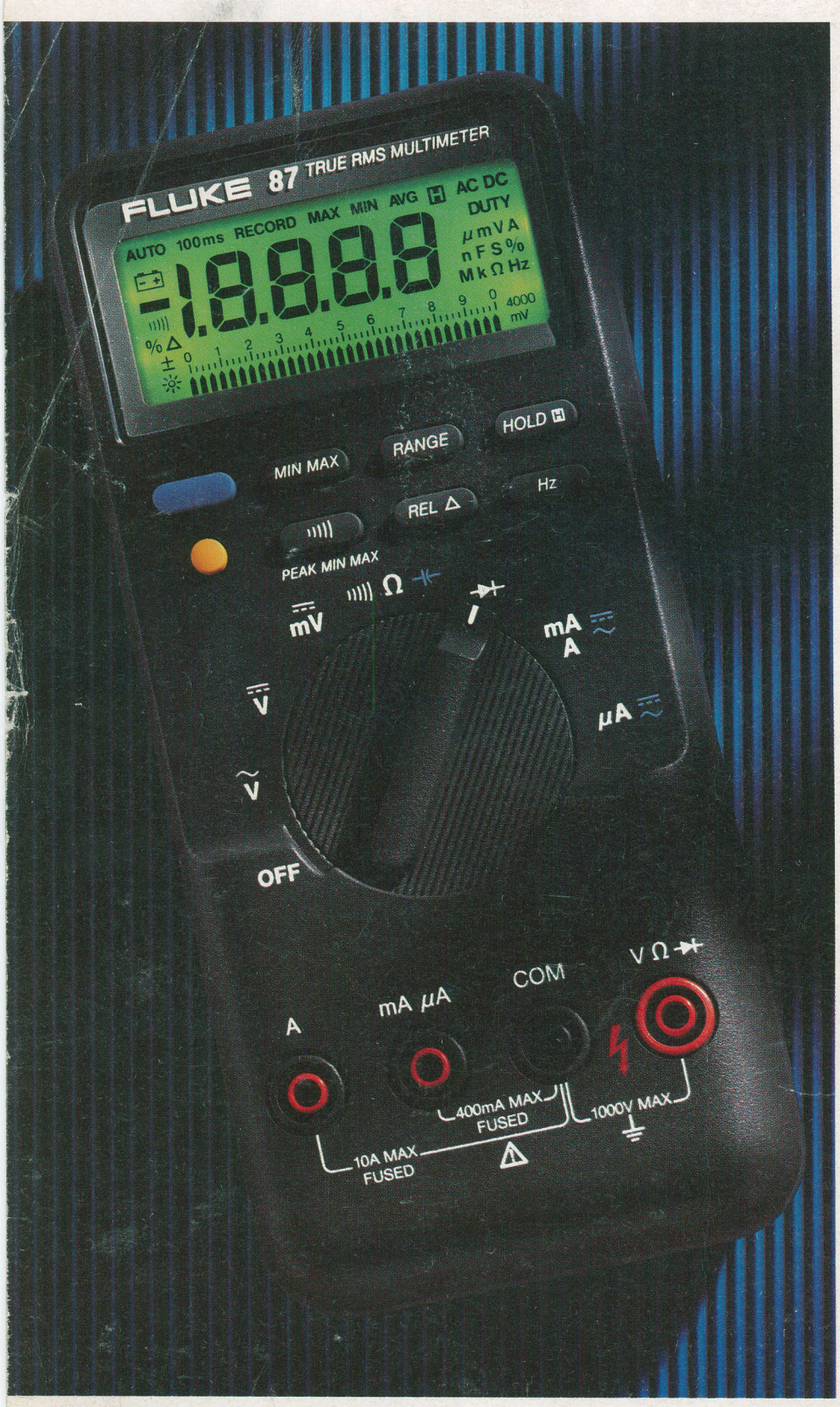

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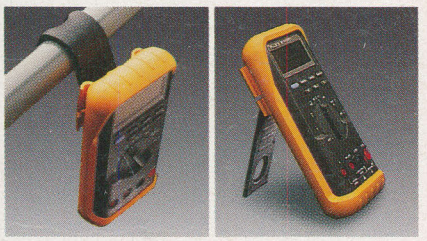

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